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Potential of Smart Glasses in a Spare Parts Distribution Center

Master's Thesis in the Master's program Supply Chain Management

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Cover: Illustration of the solution to include sorting in the picking process (Figure 5.20, p. 74).

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ABSTRACT

The distribution of products is for many manufacturing firms a necessary yet demanding and labor intensive procedure. To fulfill the role of distribution successfully, the ability to exchange information and provide workers with information plays an important part. New technologies are developed to enable better communication of information. One emerging technology is augmented reality used with smart glasses. Smart glasses aim to visually enhance reality with additional information. Therefore, it is of interest to examine how smart glasses can be used in a distribution context.

The purpose of the thesis was to identify and assess the potential of using smart glasses in Volvo Logistic Services' distribution centers processes, compared to currently used methods. To be able to achieve the purpose, a theoretical framework was developed. In addition, the distribution center processes were mapped and further data was collected through three interviews with Volvo employees, a time study and historical performance data.

The distribution center performance measures used in the thesis are productivity, quality, flexibility and ergonomics. Regarding the smart glass effect on these measures, a correlation between smart glasses and flexibility was not found. Moreover, it is concluded that smart glasses perform equally or better than current methods in regards to the performance measures. From a qualitative analysis, it is concluded that the main potential lies in using smart glasses to display additional information which today only exist through the experience of operators. Based on that statement, the potential of providing experience based information in the current distribution center processes is analyzed. Additionally, several employee suggestions of changing the processes through adding additional information is analyzed. Ultimately, two potentials were illustrated and quantified through saving estimations.

In conclusion, it is recognized that the technology is rapidly developing and that smart glasses hold large potential in the future. However, it may not be sufficient to motivate a full-scale implementation of the technology in a distribution center. Instead Volvo Logistics Services are suggested to do further investigations and a proof of concept.

Keywords: Smart Glasses, Augmented Reality, Performance Measures, Distribution Center

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1 INTRODUCTION

The introduction chapter introduces the thesis with a background explaining the development of smart glasses followed by a description of the project and the case study company. Thereafter the purpose and a problem description resulting in the thesis research questions and lastly the projects demarcations are presented.

1.1 Background

Distribution centers (DC's) have in the past been seen as fundamental cost centers, however, recent trends such as e-commerce growth and production offshoring has made them vital links in modern supply chains (Richards, 2014). The role that needs to be fulfilled for the supply chain to stay competitive is to deliver the right products, to the right customer, at the right place, at the right time, in correct quantity, in correct condition and at the right price (Richards, 2014). For a supply chain to fulfill these demands, information exchange is essential (Lambert & Cooper, 2000). It is therefore of importance for a company to provide their workers with the right information. The amount of information an individual can detect and understand simultaneously is limited. Consequently, the information must be presented in a suitable and pedagogical way to ease the workers cognitive load and ensure that all necessary information is interpreted correctly. So, it is of great importance that information is communicated in an advantageous way.

The technology development is more rapid than ever before and the time to market for new technologies is reduced for each product release. One emerging technology today is augmented reality (AR) (Glockner et al., 2014), which can be found both on Gartner's hype curve (Gartner, 2016) as well as DHL's logistics trend radar (DHL Customer Solutions & Innovation, 2016). AR can be defined as "the process of overlaying computer-generated information on reality, whether that reality is a geographic place or an object" (Berryman, 2012, p. 213). It is a technology that often is associated with smart glasses. Smart glasses can be worn like regular glasses or mounted on the head like a helmet, they capture physical information and augment it with virtual content (Philipp et al. 2015). It is usage of AR on smart glasses that will be referred to in this study, but AR can be used with a range of display devices such as mobile phones (Berryman, 2012). By definition AR differs from virtual reality since reality is a primary component of AR, unlike virtual reality where the users do not experience any interaction with the real world (Berryman, 2012; Borsci et al., 2015). Virtual reality on smart glasses is by the industry mostly used for product development and training of operators (Berg & Vance, 2016).

According to Regenbrecht et al. (2005) both academic and industry partners acknowledge a great potential for smart glasses in many applications. Applications range from design to entertainment, training and logistics, with the goal to enrich human ability and senses in the real world by providing supporting information (Cirulis & Ginters, 2013). So, the question remains what is the potential with this new information sharing technology? Looking at distribution, the time a supplier has to respond to customer demand generally decreases (de Koster et al., 2007). This necessitates that workers can improve without increased stress or deteriorated quality, which smart glasses with intuitive visual support have potential to do (Schwerdtfeger et al., 2011). Rief & Walch (2008) state that smart glasses should be investigated to find new possibilities to further optimize logistics processes and Ginters & Martin-

Gutierrez (2013) writes they are likely to be used in warehouses and large-scale manufacturing systems in a near future. In fact, there is already today examples of commercialization of smart glasses within logistics processes, for example companies providing smart glasses solutions for order picking processes (DHL International, 2015). These companies advertise in their sales pitch benefits of the technology such as faster picking time, increased accuracy, lower cost and high employee acceptance level (Evolar, 2014; Ubimax GmbH, 2017; Pcdata BV, 2016; Picavi GmbH, 2016). However, Ginters & Martin-Gutierrez (2013) acknowledge that the ergonomics of the hardware and the efficiency of the software needs to be further refined before the solutions will be implemented in larger scales.

In conclusion, smart glasses are an emerging technology which has received increasing attention. Furthermore, both the industry as well as researchers sees great potential with the technology. It is therefore interesting to evaluate whether the technology could be beneficial to implement in a DC and what effect the increasing information sharing could provide. To objectively assess the technology towards existing solutions, analyze the prerequisites and potential of the technology for a given situation, which in the thesis is a Volvo Group spare parts DC in Sweden complemented with some processes from a European Central DC.

1.2 Project Description

The project was carried out on behalf of Volvo Logistics Services (Volvo LS), which is part of the Volvo Group and the group’s lead logistics provider. One of Volvo LS’ areas of responsibility is to continuously seek for more cost effective logistics solutions. As an aid in this search, the project included an examination of how smart glasses could benefit the company's DC operations. The conducted analysis of the usability of smart glasses for a DC can be said to consist of three parts. The parts are an analysis of smart glasses as a substitute for current used technology, exploration of additional possibilities for smart glasses to provide value and lastly a quantification of the potential of two examples. Data has been collected from two different DCs in the project. Based on its convenient location, the first and primarily investigated DC is located Eskilstuna, Sweden. Here scanners and paper are currently the primary methods used to communicate information to operators. The second DC is a central DC (CDC) located in Gent, Belgium. Complementing data is collected from the CDC since Volvo LS’ current best practice voice technology is used there. Furthermore, it is a larger DC with slightly different purpose and therefore carries out some processes which were observed that the DC in Eskilstuna does not have in a large scale.

1.3 Purpose

The purpose of the thesis was to identify and assess the potential of using smart glasses in Volvo Logistics Services’ distribution center processes, compared to currently used methods.

1.4 Problem Description and Research Questions

To understand how the potentials, of using smart glasses within the processes in a DC, could be identified and assessed measures to evaluate the processes in a DC was needed. Moreover, how smart glasses affect those measures was an important factor for the study. Therefore was the first research question formulated:

RQ1: What performance measures are used to evaluate a DC and how do smart glasses affect those measures?

To identify in what processes the main potential could be identified, the processes in the DC´s needed to be mapped. The mapping provided an overview to understand how the DC's currently operated and what information that currently existed in the processes. It was first when knowing the information currently used by operators in the DC processes that the potential of communicating that information with smart glasses could be assessed. The second research question was then raised as:

RQ2: What information is beneficial to communicate with smart glasses?

To assess the potential of using smart glasses a comparison with the current methods was needed as well as a quantification of expected gains from an implementation. The quantification provided an indication of the potential of specific suggestions and a thorough description and illustration was beneficial. Therefore was the third research question:

RQ3: How could a solution look like and what gains can be derived from an implementation?

1.5 Demarcations

The project focused on elaborating on whether or not smart glasses should be used in Volvo LS' spare part DCs, meaning that the company plays a central role in the study. Nevertheless, the thesis contributes to research with a qualitative analysis of how a relatively new technology could be used and provides value in an industrial setting. Because the settings, processes and data of two specific DCs were used in the analysis, it may not be applicable to other DC's. However, it should provide relevant considerations since the performance measures used as a basis of analysis are relevant also for other DCs.

Due to the complexity of the processes carried out at the spare parts DCs of Volvo LS, some simplifications have been made to make the content of the thesis lighter and more understandable for readers. Furthermore, Volvo LS continuously works with improving their operations, meaning that the context will eventually change from the context of which data has been gathered. These changes may affect the relevance of the study and has not been taken into consideration.

Important to note is that AR smart glasses is the central reference point in the thesis, meaning that VR technology is not treated nor is other devices that can be used to augment reality such as mobile phones. This is because of time constraints and that AR smart glasses are thought to be conceptually better fit for use in DC operations. By definition, smart glasses are a technology that enhances reality by displaying additional information on top of it. Generally the glasses themselves do not produce the information but rather communicate it. In the thesis, focus has been on the display of information with use of smart glasses rather than investigating the information handling in Volvos LS' warehouse management system (WMS) or confirmation solutions needed as a complement to smart glasses. This implies that the analysis of the investigated suggestions does not include issues related to integration with the

WMS system. Furthermore, the thesis does not evaluate other technologies that may be used to improve the efficiency of Volvo LS' DC operations such as automation. Although, a discussion is included regarding a few technologies that may hinder or replace the use of smart glasses in DCs.

1.6 Thesis Disposition

The thesis disposition and the content in the separate parts are described and presented in Table 1.1. Each of the parts starts with an introduction introducing the outline and content of that part.

Table 1.1: Thesis disposition

1 Introduction	The introduction introduces the research area and motivates the thesis. The purpose, research questions and demarcations are presented.
2 Theoretical Framework	The theoretical framework includes findings from previous research relevant for the thesis. These findings are compiled into the conceptual framework.
3 Methodology	The methodology describes the research process and the method used for the thesis. The collection and selection of both empirical data and previous research is included.
4 Empirical Data	The empirical data present all of the data gathered and used for the thesis. It includes the mappings of the DC processes, historical data and the time study result.
5 Analysis	The analysis presents the result of the thesis. An explanation of the three analysis steps and the concluding result of each step are presented.
6 Discussion	Initially, the methodology and the result are discussed. Thereafter, implications for future research, additional potentials and future development are discussed.
7 Conclusion	The conclusion presents the resulting answers to the given research questions. Further, a concluding statement is made regarding the thesis purpose.

2 THEORETICAL FRAMEWORK

The theoretical framework is divided into four parts. The first chapter introduce information interaction and different methods to communicate information to operators within a warehouse. Chapter 2.2 present the performance measures that are to be used to evaluate the DC performances. Thereafter chapter 2.3 states how smart glasses affect the performance measures from chapter 2.3. Lastly, the theoretical framework ends with the conceptual framework illustrating how chapter 2.2 and 2.3 are connected.

2.1 Information Interaction

All information that humans obtain from the outside world is provided through one of the five senses; sight, hearing, smell, touch or taste. These are portals of raw information about the environment that enables humans to interact with it. In general, humans obtain information from mainly sight and hearing, each representing respectively about 80 and 10 percent of the total processing capability (Stolovitch et al., 2011). The processing capability here refers to the amount of sensory information that a human can gather with a given unit of time. Thus, humans are more efficient at gathering information through our sight, being able to take in more information in the same time period compared to other senses. When receiving information through our sight how effectively an individual can interpret and understand the information is dependent on the way it is presented (Spence, 2014). To ease the understanding, the presented information should be arranged in a logical way and simplified with the use of colors and visual attributes.

The operations of a DC is typically labor intensive, with some of them being extremely difficult and expensive to automate, which is why human labor is often used in DCs (Bartholdi & Hackman, 2016). The extent or quality to which operators are able to carry out these tasks is connected to what information they receive as well as its' accuracy and how it is interpreted (Hollnagel, 1997). Table 2.1 presents a list of different information types found in warehouse operations literature that could be beneficial or even necessary for operators to have in one or more of the processes conducted in the DC.

Table 2.1: Types of information in a DC (Bartholdi & Hackman (2016); Grosse & Glock (2015); Hompel & Schmidt (2007); Shiau & Lee (2010)).

Information	
Goods arrival	Notification that goods have arrived
Order arrival	Items, quantities and customer
SKU dimensions	Length, width and height of the part
Container dimensions	Length, width and height of the shipping container
SKU weight	The parts weight
Container weight	The shipping containers weight
Container selection	The optimal shipping container to chose
Special handling	Need for different handling due to characteristics of the part

SKU turnover rate	Frequency of the part
Inspection information	The information used to make an inspection of the part
Order line SKU quantity	The number of items ordered
SKU shelf position	The specific location of the part in the warehouse
Routing instruction	Path instructions to specific location
DC layout	The layout in the DC, pathways and work stations
Process Sequence	The sequence in which the process steps are performed
Loading sequence	The sequence in which the shipments are loaded
Process technical capacity	The capacity of a given process
Work load (by zones)	The amount of work for a station, related to the man power
Travel distance	The distance between two locations
Service requirements	Customer requirements
Staging information	Limitations and possibilities regarding staging

2.1.1 Conventional Information Interaction Methods

Conventionally, warehouse operations have been executed with instructions printed on paper lists, which is intuitive but tiring and inefficient (Reif & Günthner, 2009). Information sharing between the operators and the warehouse management system (WMS) is an important operation that can be handled with different devices. In this chapter the most common methods to make information accessible in Volvos warehouses are presented.

A widespread method for paperless handling applied in the industry is handheld barcode scanners (Andriolo et al., 2016). The operator receives information through a display. To verify and confirm a task, the operator scans a barcode tag corresponding to for example an item or a stock location (Andriolo et al., 2016). The main advantages of this method compared to a paper picking list is the ease of use (Andriolo et al., 2016), reduced time to complete the task (Grosse et al., 2015) and less errors (Brynzér & Johansson, 1995). This is an intuitive solution since operators recognize the technology and understand how it works. The reduction of the time required for a task is derived from a reduction of the time needed for information input and identification. Instead of searching for the right positions, writing down quantities and checking part numbers, barcodes on the items and shelf positions can be scanned, providing direct feedback to the operator. Further, information about a task is provided in the display when a task barcode is scanned. Traditionally, the workers need to hold the scanner and can therefore only can pick with one hand, which results in lower picking efficiency. Furthermore, to not require multiple tries to scan the barcodes, due to insufficiently readable barcodes, a high-contrast and clean environment are prerequisites (McFarlane & Sheffi, 2003). So, the information is communicated through a display and the users confirm the actions performed with the scanning of a barcode.

Another method that has grown to be a viable solution is pick-by-voice (Park, 2012). In the voice system all operators are equipped with a headset to receive instructions for the task to be performed in real time and a microphone to verbally confirm the actions back to the system (Andriolo et al., 2016). The instructions can guide the user to a location, provide a quantity and demand response from the user. To confirm the tasks performed and receive the next instruction the worker answer into the microphone. The system use speech recognition to understand the user and register what actions the operator performed (Battini et al., 2015). An advantage with this system compared to the scanner solution is the ability to work with both hands (Andriolo et al., 2016). However, whether the operator likes being told what to do by a monotone voice during a full workday is unclear and in noisy industrial environments the system faces difficulties, since it is reliant on verbal instructions and responses (Reif & Günthner, 2009).

One difference between solutions is the sequence in which the actions are performed (Battini et al., 2015). For the scanner the activities from receiving the information about a task to confirming the action is performed consecutively, but for a voice system the action and confirmation can be done simultaneously. However, Andriolo et al. (2016) state the importance to adapt the solution to the needs of the warehouse. All situations will require different configurations and applications tailored to fit the expected performance and technological limits.

2.1.2 Smart Glasses as an Interaction Method

As described in the introduction, there are several methods to use AR for different applications. One method that can be used for non-stationary, hands-free applications are smart glasses, sometimes referred to as head mounted displays (Glockner et al., 2014). Essentially, smart glasses are usually worn like regular glasses but can also be mounted on the head like a helmet, often referred to as head mounted displays in that case. Using several devices such as screens, network interface cards, cameras and microphones, smart glasses are able to capture physical information and augment it with virtual content (Philipp et al. 2015).

The technology is relatively new and therefore there is no universally accepted definition for AR. However, the thesis used the definition of Berryman (2012, p. 213) were AR is defined as “the process of overlaying computer-generated information on reality, whether that reality is a geographic place or an object”. It is worth mentioning that the available hardware solutions offer different functionalities and levels of interaction with reality, henceforth referred to as different levels of AR. The levels range from overlaying physical reality with two-dimensional digital content to interact with the physical reality and display three-dimensional content to the user. For the user using smart glasses this could be exemplified as being able to see a picture of a product in his field of view to place a virtual product on top of a table next to him. Smart glasses can display information about a system virtually for the user. However, to communicate back to the system the smart glasses will have to be combined with another solution, like radio frequency identification (RFID) or voice system (Fager 2016; Reif & Günthner, 2009).

There is a wide range of smart glasses manufacturers today including Sony, Epson, Vuzix and many more (Lamkin & Charara, 2017), that use two dimensional AR with low level of environment interaction. One of the first commercial and perhaps most well-known example is the Google Glass. The Google Glass contains one small see-through prism in the upper or middle-right corner of the vision field, equivalent to a 25 inch screen distanced eight feet from the user (Google, 2017). In practice, it works like a regular screen monitor displaying two-dimensional information. The device furthermore contains a camera that can capture what the user is seeing, microphones for voice control and a network card to access Wi-Fi or Bluetooth (Google, 2017). The battery life is stated to last for one day, but perhaps more realistically lasts five hours, with a recharge time of about one hour. To interact with the Google Glass, users can utilize a touchpad at the side of the glasses but also to some extent voice command and head movement (Google, 2017). Because the glasses have a camera, a simple form interaction through making hand gestures and identification by reading barcodes or QR codes could be achieved through third party applications, which are functionalities created by external parties.

One of the perhaps most prominent products using three dimensional and interacting smart glasses is the Microsoft Hololens, which however yet only exists as a developer edition. The Hololens contain two special transparent holographic display lenses in the middle of the field of view, an inertial measurement unit to track any movement, cameras that can the read surrounding environment and microphones to enable voice control (Microsoft, 2017b). Furthermore, the Hololens has the ability to communicate through Wi-Fi and Bluetooth and has a battery life of about two hours. The Hololens display lenses are made so that they can create an effective optical illusion for the user (Taylor, 2016). This means that both two and three dimensional virtual objects can appear as they are at various positions and distances in the room, blended with reality instead of being superimposed on top of reality. The objects, or holograms, can be solid as well as semitransparent and the technology allows the user to walk around the holograms to inspect every angle (Taylor, 2016). Because the Hololens can scan and map the surrounding environment, holograms are able to interact realistically with the real-world. Furthermore, the user is able to interact with the holograms in a natural way through voice controls, gaze tracking and custom gestures (Avila & Bailey, 2016). In practice, this means that the Hololens can create both objects that do not exist into the room from drawings and place screens with information wherever the user desires.

2.2 Distribution Center Performance

To compare different solutions or methods, it is important to understand the related requirements and performance objectives. However, to do that it is important to have knowledge about the different processes found in a warehouse. These processes can be defined in many ways and include many different types of activities depending on the context, however the generic case can be described with the following processes: unloading, putaway, picking and loading (Berg & Zijm, 1999; Gu et al., 2007). Other activities which often can be found to be included are the sortation and packing of products or value adding services (Berg & Zijm, 1999). Unloading and loading are the interface of a DC's material flows and involve, for example, scheduling loading activities (Gu et al., 2007). Putaway is about organizing the SKU's in a manner that aims to achieve efficient material handling and good space utilization (Gu et al., 2007). The picking process is defined by de Koster et al. (2007, p 481) as "The process of retrieving products from storage (or buffer areas) in response to a specific customer request". Picking usually described as the undoubtedly most expensive operating expense, as typically about 55 % of warehouse operating costs are attributed to the process (Bartholdi & Hackman, 2016). The order picking time can then be further broken down to into 15% spent on searching, 10% extracting SKUs and the remainder is spent on traveling or other.

Compiled from supply chain, warehouse operation and related research areas, Figure 2.1 provides the perspective on distribution center performance used in the thesis. The framework presented consists of the three, within logistics research often used, performance dimensions, productivity, quality and flexibility (Stainer, 1997; Fager, 2016; Staudt, 2015). In addition, a fourth dimension, ergonomics, is included within the framework to enable the evaluation of the potential with smart glasses and its importance to Volvo LS.

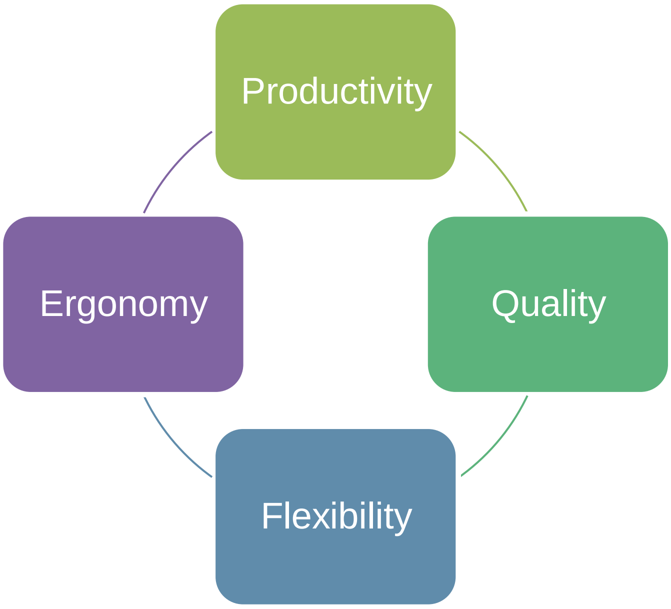

Figure 2.1: Performance measures

To identify the potential of smart glasses in a DC environment it is essential to evaluate the long-term profitability of implementing smart glasses. This is connected to the ability to use the existing resources, economic as well as social, resulting in productivity and ergonomics. To have a long-term view it is important to maintain enough flexibility in an ever changing environment and to deliver the service that the customers expect and demand, resulting in flexibility and quality. Each of the dimensions are discussed separately within this chapter.

2.2.1 Productivity

As a means to assess how well or efficiently a system operates, productivity is a commonly used measurement (Park, 2012). Productivity is generally defined as the ratio between system output and system input, which means that any changes of productivity is directly related to the amount of resources needed to achieve a given output level. An increase of productivity could therefore economically motivate an investment.

In the case of a warehouse, both Bartholdi and Hackman (2016) and Park (2012) explain the critical input resource as space and time. Although depending on operation context, the output is usually measured in units such as completed order lines, orders, transactions, pieces or pallets (Hackman et al., 2001; Park 2012). The productivity objective is therefore to maximize the amount of units handled to the lowest total cost. Therefore, there are two main types of productivity measures found to often be used for warehouse operations. One is space efficiency, meaning how much storage space that is available compared to area used (Bartholdi & Hackman, 2016; Park, 2012). Secondly, there is throughput, meaning the maximum, average long-run rate that a system can process requests (Park, 2012). A commonly used example within broken case picking warehouses are therefore the number of order lines processed per labor hour spent (Mentzer & Konrad, 1991).

2.2.2 Quality

While how efficiently resources are used in a warehouse plays an important role to the company profitability, the question of whether or not it is able to meet customer requirements is perhaps even more important. As described by Bartholdi and Hackman (2016), inaccurate order fulfillment can lead to much dissatisfaction and losses for the customer. Furthermore, it generates returns which can cost ten times more than shipping the product out, which is why quality is an essential measurement.

As stated by Richards (2014), a supply chain must be able to meet certain quality requirements to stay competitive. However, even within one single organization, quality can be defined in several different ways since it is concerned with customers' perception of quality. It can therefore be said to measure the degree to which customer expectations are met (Fager, 2016).

Within warehouse application, there is two commonly used measurements and by Park (2012) described as most important. These are order lead time and delivery accuracy. Order lead time is defined as the time interval from request release to floor until request completion. Because this measurement is directly affected by how fast order lines can be handled, it is closely related to productivity. Delivery accuracy is defined as the percentage of error-free deliveries (de Koster and Warffemius, 2005). What defines an error-free delivery here could be explained as the delivery of right item in the right quantity (Battini et al., 2015). The right item is interpreted as the by customer ordered item in an acceptable condition. Worth noting is that Bartholdi and Hackman (2016) state that it is typically advantageous to do quality checks in the packing process, as it is typically the last process where each item is handled separately.

2.2.3 Flexibility

Richardson (1998) describe that the environment, in which distribution centers operate, changes over time. It is therefore of essence to consider how susceptible the warehouse design is to different changes. Further, as stated by Bartholdi and Hackman (2016), inflexible warehouse systems can be very expensive to adapt to changes made to the business. However, it seems that previous research agrees that flexibility is a rather complex and multidimensional concept, with diverse sets of types and terms (Aprile et al., 2005; Fager, 2016). Perhaps as a result of the complexity of flexibility, as also pointed out by Aprile et al. (2005), previous research within the supply chain area often only investigate flexibility within specific manufacturing systems. To achieve a comprehensive framework for flexibility, the types of flexibility are therefore compiled both from supply chain and manufacturing flexibility, where it is relatable to DC applications.

Changes that can be related to warehouse operations and that induces demand for flexibility includes: introduction of new products (Slack, 2005; Fager, 2016), change of route (Viswanadham & Raghava, 1997; Jafari, 2014), volume variation (Slack, 2005; Tachizawa & Thomsen, 2007) and changes to product mix (Brockmann, 1997; Tachizawa & Thomsen, 2007; Jafari, 2014). Furthermore, since any decisions made today are based on the current conditions which might change in the future, there is a point in discussing the ability to make modifications of processes or warehouse layout and how locked a party becomes when choosing a specific technology to use (Brockmann, 1997; Arthur, 1998).

The six different types of flexibility relatable to warehouse operations are listed and defined in Table 2.2. The first four of the flexibility types address flexibility in the short term while the last two are connected to more long term flexibility implications. Firstly, both product and mix flexibility is introduced by Slack (2005) as important flexibility types. They can be considered in a warehouse environment with regards to the product range kept in stock and the effort that is needed to change the product range, which might include introducing new products or arranging product storage layout based demand lifecycle. Another dimension of product flexibility is concerned with what Brockmann (1997) states as the warehouse ability to manage multiple SKU characteristics, such as varying weight or size. When referring to the route flexibility, Viswanadham and Raghava (1997) writes about the ability to perform activities in more locations than one and the number of ways an order can be filled, while for a warehouse it may rather be concerned with the opportunity to adapt the route to the current warehouse situation. Flexibility can also be considered for how adaptable they are to changes in demand volume, both in short and long term (Viswanadham & Raghava, 1997).

Table 2.2: Flexibility types with definitions

Flexibility type	Definition Used
Product	Ability to introduce novel products - Slack (2005) Ability to handle changes to product characteristics - Brockmann (1997)
Mix	Ability to change the range of products - Slack (2005)
Route	Ability to use alternative routes - Viswanadham and Raghava (1997)
Volume	Ability of system to adjust output level according to demand - Viswanadham and Raghava (1997)
Modification	Ability to allow changes in warehouse layout and operation - Brockmann (1997)
Locked-in	Ability of a party to change from an previously adopted technology or solution - Arthur (1998)

Modification is concerned with what Brockmann (1997) explains as flexibility to adapt layout and operation to changing circumstances, whether it means that additional processes are added, such as value adding activities, or if it means changes to the material handling. Locked-in is defined as the flexibility of changing solution or technology that previously has been adopted, which is discussed by Arthur (1998). It is of importance when considering the long term profitability and if the solution becomes outdated or needs to be used in other contexts, for example in other warehouses. So, modification is connected to how the solution can be changed and adapted to market changes while locked-in concern the ability to change to an alternative solution to respond to an ever changing environment.

2.2.4 Ergonomics

Karwowski (2001) writes that even in industrialized countries, human resources are not always used in a sustainable way. Especially in changing business environments where the turbulence is countered with increased work intensity, human resources can be affected. However, ergonomic work design can contribute to preservation or increase of human and social capital (Karwowski, 2001), which is why it is an important aspect.

Ergonomics can be divided into two types, traditional ergonomics concerning how workers are affected by the physical work design or conditions and cognitive ergonomics, meaning how the work and mind affect each other (Hollnagel, 1997). Traditional ergonomics often deal with work design risks in form of noise level, light, posture, loads or pace and how it can negatively affect or injure the worker (Eklund, 2010; Rostykus et al., 2016; Marklin & Wilzbacher, 1999). Rostykus et al. (2016) as well as Marklin and Wilzbacher focus on this type of ergonomics and examine injury which commonly arises from too harsh occupational wear and tear on the body. Rostykus et al. (2016) describes three primary risks factors which are awkward postures, high loads and long duration or high frequency where two or three of these factors in combination increase the risk of developing discomfort or injuries. Marklin and Wilzbacher (1999) developed a framework that includes factors such as asymmetry, frequency and load as important factors when measuring ergonomics.

Across many industries a shift can be seen where work has become less physical and more about work with the mind, which affects humans in a different way and can lead to for example stress or sleep disorders if the workload is too high (Hollnagel, 1997). That development has emphasized cognitive ergonomics aspects and as Hollnagel (1997) writes, risks within cognitive ergonomics refer to the working condition aspects that may lead to unwanted outcomes. As the outcome or performance of a task is dependent on the executors understanding of the situation, the objective is to provide right information, in right format and at right time. Hollnagel (1997) further explains that the information needs to be comprehensive, trustworthy, meet expectation and be useful for users to actually use it and be comfortable with it.

2.3 Smart Glasses Effects on the Performance Measures

Studies have been performed by multiple researchers to compare and analyze the benefits gained from smart glasses, as well as the drawbacks with an implementation. Within most of the research found regarding smart glasses and how it affects warehouse operation productivity, order picking is the main or only examined process. This might be attributed to the fact that order picking is by far the most expensive operation of a warehouse, typically about 55 percent of the operating costs (Frazelle, 2016). The different studies referred to in this section have been performed within a limited laboratory environment, which affects the conclusions that can be drawn. The levels of AR used for the smart glasses in these studies range from two-dimensional support without interaction with the reality to three-dimensional support that interacts with the surroundings. Regardless of the level of AR used the results from the studies has been similar. This implies that the effects of the different performance measures are not significantly affected by the level of AR. Hence, no division of the results of the studies has been made based on the level of AR.

Moreover, the different methods that are compared to picking with smart glasses within the studies are pick-by-list, pick-by-light and pick-by-voice (Fager, 2016; Guo et al., 2015; Reif & Günthner, 2009; Reif & Walch, 2008; Weaver et al., 2010). However, except for the conventional methods a cart-mounted display (Guo et al., 2015), a graphical picklist (Weaver et al., 2010) and a virtual reality solution (Reif & Walch, 2008) has been used to evaluate the performance of pick-by-vision. The effects linked to flexibility will not be covered in this section, because of an existing gap of research regarding smart glasses and that performance measure. However, how the use of smart glasses can affect flexibility is examined in the empirical study (Chapter 4.3).

2.3.1 Smart Glasses Effect on Productivity

The implementation of a smart glass-solution within a DC will affect the productivity for the affected process. However, previous research has provided results that indicate that the technology is competitive and at least performs equally well. This can be explained both by the fact that the time needed to understand the information and also search for items and positions can be reduced (Schwerdtfeger et al., 2011).

So, the time it takes to understand and interpret the information needed to perform the assigned task can be reduced with the use of smart glasses (Baumann et al., 2011; Schwerdtfeger et al., 2011). This can be explained since smart glasses facilitate the use of visual attributes which is often to some extent used for a solution. If the instructions are visualized the efficiency will increase compared to both written and verbal instructions (Schwerdtfeger et al., 2011). Even if visualizations are superior compared to other information sources, Schwerdtfeger and Klinker (2008) realized with their study that the quality of graphics in the smart glasses is important for the users performance. The same graphical solutions provided better result with an improved smart glasses solution. This result can be derived from either better hardware or software solutions (Schwerdtfeger & Klinker, 2008). However, it is not only the graphical presentation of information that results in faster picking times. Another clear advantage that reduces the time needed for each task is the ability to use both hands (Weaver et al., 2010). The advantage enable the user to handle heavier products and larger quantities more time efficient, without increasing the risks of repetitive strain injuries.

Since the time a worker need to search for a position or an item can be reduced with an enhanced way to present information, improved productivity can be achieved with smart glasses (Glockner et al., 2014; Reif & Günthner, 2009). Either with graphical guidance to the position or illustrations that are simple and easily can be translated to match the reality. So, there are possibilities to improve the productivity in DC operations with the use of smart glasses. Weaver et al. (2010) acknowledge that the average time to complete a task was significantly faster with pick-by-vision. This is also concluded by Fager (2016) that describe pick-by-vision as a competitive method compared to alternative solutions. Moreover, by having the information present in the user's field of view the need to move to receive instructions will disappear. Thus, the efficiency of every worker will increase since the number of steps needed to do one pick can be reduced with a well thought through implementation of smart glasses (Guo et al., 2015).

2.3.2 Smart Glasses Effect on Quality

The most prominent results from previous research are how the number of errors can be reduced with the use of smart glasses. All of the researchers present a result indicating that smart glasses improved the quality compared to alternative solutions. This is both in regards to fewer mispicks of the items as well as better handling of the items (Reif & Walch, 2008). The improved quality can be derived from lower cognitive load for the user allowing for improved support with the use of pictures and colors (Baumann et al., 2011). So, smart glasses can provide the user with detailed work instructions in a precise and intuitive way (Schwerdtfeger et al., 2011). The increased quality can further be explained since necessary information will be available for the user during the completion of the task (Weaver et al., 2010). Therefore, the user will not have to look at instructions to then move and perform the task. Besides the advantage of a reduction of errors, the quality mistakes that did occur with the use of smart glasses tended to be less severe (Guo et al., 2015). This is because the mistake made with smart glasses mainly is that the wrong quantity is picked. The less severe mistakes can be explained by the fact that the users have access to the instructions while performing the task.

Smart glasses will enable the sharing of additional information to the user (Thomas & Sandor, 2009). Therefore can, except for fewer errors, smart glasses enables better handling based on the specific product characteristics. This better handling will reduce mistakes that occur based on specific product characteristics, examples of that is multiples or fragile products. So, a worker will not be required to have knowledge about exceptions and how these needs to be handle since that information, given that it exists, can be displayed in the smart glasses. Moreover, the use of smart glasses provides means for information gathering about the different tasks (Reif & Günthner, 2009). Smart glasses could for example record how the process is performed for products where mistakes are more common. This information can later be used to better analyze why mistakes are made and how to mitigate them from happen.

2.3.3 Smart Glasses Effect on Ergonomics

To bring smart glasses into operations it is necessary to consider that the worker will have to wear the device during a full eight hours workday. Because of that it is crucial that the smart glasses are ergonomically designed (Reif & Walch, 2008). Thomas and Sandor (2009) acknowledge the less aesthetic design of some of the devices on the market today. This insufficient design may lead to resistance from the users.

Another functional limit for smart glasses is the limitation of the user's field of view (Thomas & Sandor, 2009). This will be differently for the smart glasses solutions. By providing additional information regarding the product, the worker has the ability to prepare for the task and use appropriate approaches and equipment. While using Google Glass and its graphics display, the remainder of the field of vision will be out of focus. For the Microsoft Hololens, the graphical content will interact with the user's field of view and therefore partly limit the information the user can detect from reality. This is both because the graphical content physically can block out real content as well as divide the user's attention, so the reality might prove more difficult to notice. If the Hololens interact with reality it requires the user to look at the right direction to receive the instructions, if that is not the case some orientation feature is required to help the user (Schwerdtfeger et al., 2011). Furthermore, except being dangerous if the user miss crucial information, to have something partly blocking the vision may interfere with the user's social interaction with other colleagues. Due (2014) state that it from interviews had been revealed that two thirds felt uncomfortable by using smart glasses and interacting with others. However, this leaves according to Due (2014) one third that already today think that interaction with others can occur seamless with the technology. Interacting with colleagues with smart glasses is equated with looking at a phone while interacting with other people simultaneously, so there is a highlighted obstacle.

Users stated that the smart glasses solution resulted in less work to perform the same task making it preferable compared to alternative solutions (Guo et al., 2015). This is because smart glasses can provide precise instructions in an intuitive way (Schwerdtfeger et al., 2011). The information is easier for the user to understand due to the use of pictures, colors and symbols. So, Baumann et al. (2011) acknowledge that an implementation of smart glasses can lower the cognitive load for an operator. However, the study further implies that too much information will confuse the user and both reduce the picking efficiency as well as the picking quality. Furthermore, the users stated that the preferred solutions did not have too much information. Weaver et al. (2010) recognize that a major advantage of this solution is the enhanced information sharing combined with the benefit of availability of the information. The use of detailed and descriptive information like pictures was especially beneficial and appreciated in unfamiliar environments (Baumann et al., 2011). Moreover, Weaver et al. (2010) measured how the users perceived their own performance when using pick-by-vision compared to the alternative solutions in the study. This result indicated that the users were fairly good at estimating their performance both regarding speed and accuracy. The users also gave an opinion of the alternatives based on learnability and comfort, were pick-by-vision were perceived preferable regarding comfort and not significantly harder to learn.

Another benefit is that the user is able to work with both hands due to the hands free information support (Glockner et al., 2014; Weaver et al., 2010). This will enable the users to lift items in a more appropriate way to avoid uneven strain and repetitive strain injuries. Furthermore, the technology was within the studies highly accepted and a motivation to the users (Reif & Walch, 2008), which entails a steep learning curve (Reif & Günthner, 2009). A steep learning curve is advantageous for an environment with high turnover rates or the use of an agency to deal with demand fluctuations and sick leave.

Furthermore, one highly important usability factor for smart glasses is connected to the prevention of injuries and accidents. The question whether it could be harmful for the human eye to work a full day with smart glasses or not is still unanswered (Klein-Theyer et al., 2016). Independently of the effect on the human eye, some users experience serious problems watching and reading instructions from the smart glasses (Schwerdtfeger et al., 2011). Klein-Theyer et al. (2016) discovered that smart glasses to some extent affect the human eye when used for a longer time period. However exactly what the effects are in the long run is still unclear and further research is needed. Peli (1998) discovered when investigating head mounted displays that there were no significant difference between the effects on the eye from this technology compared to a desk-top display. The study stated that no harmful or significant change to the visual system could be associated with the use of the head mounted displays, either in mono or stereo mode.

Because of the continuous interaction needed between the worker and the surrounding environment the graphics provided in the smart glasses is not allowed to limit the user's field of view (Reif & Günthner, 2009; Schwerdtfeger et al., 2011). Furthermore, it is of importance that the user simultaneously distinguishes both the supporting graphics and important elements in reality. It therefore becomes of interest to investigate how smart glasses affect other simultaneous activities. Although humans are able to process much information through eyesight, the visual attention of humans need to be distributed when distinct tasks are carried out simultaneously.

To find the correlation of how the visual attention is affected by carrying out several tasks simultaneously and to determine whether AR can be used safely while operating vehicles, Sun et al., (2015) conducted two experiments. The experiments indicate that the amount of information displayed to the user has an inverse correlation to the performance of a user. Sun et al. (2015) describes that the visual attention of users will be divided and the performance thus lowered, meaning that there are significant safety concerns using AR while driving. However, Liu and Wen (2004) come to the realization that some information must be received despite that it increases cognitive load, for example navigation, road signs and speed. Liu and Wen (2004) compare the use of AR in the user's line of sight with a regular dashboard display and conclude that the former method allows users to respond quicker, more consistently and cause less mental stress. This is further motivated in the study by Tippey et al. (2017), that conclude that interaction with smart glasses perform better in terms of safety while driving, compared to using a mobile device.

2.4 Conceptual Framework

The literature review was summarize and concluded into a framework (Figure 2.2), which was used as a foundation for the analysis of the study. Based on the four performance measures literature about smart glasses were examined. However, there was no references found that discussed how smart glasses affect flexibility. One hypothesis derived from that discovery is that smart glasses might not affect the flexibility of the system compared to the investigated alternatives.

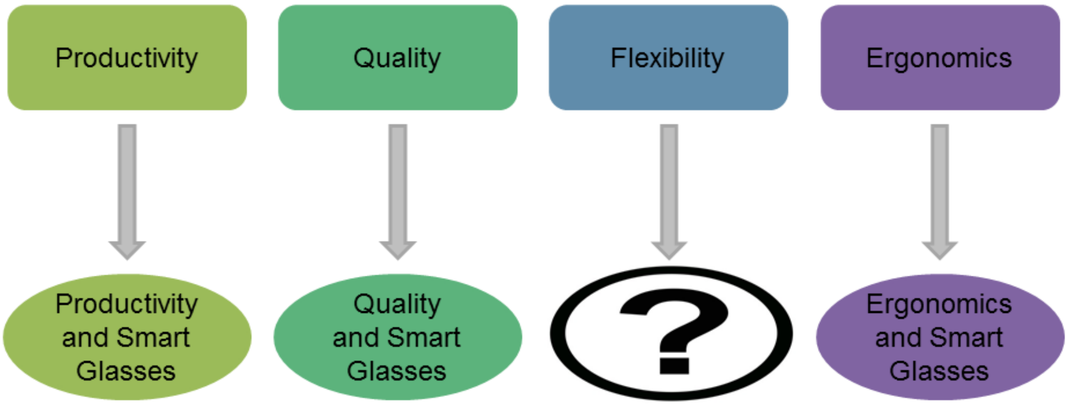

Figure 2.2: The conceptual framework for the study

3 METHODOLOGY

The method chapter presents the research process and method used in the thesis to facilitate an understanding of the work progress. This includes the selection and collection of both empirical data and previous research. Lastly, the source credibility is discussed.

3.1 Research Process

The research was conducted in three steps: *investigation of research area*, *mapping of DC processes* and *investigation of potentials*. Either primary or secondary data collection was conducted within each of the steps (Figure 3.1). The steps were not carried out in a sequential manner, but rather in an iterative process. As support for the authors, a steering committee with supervisors from Chalmers and Volvo LS has been consulted continuously.

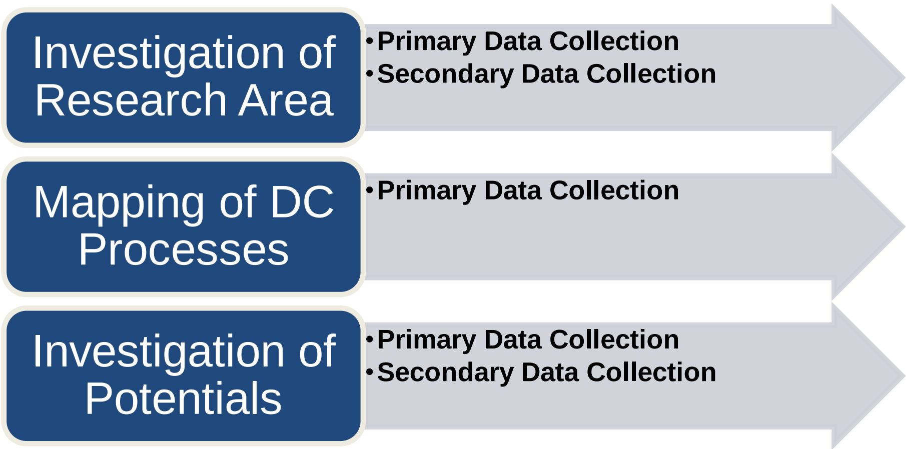

Figure 3.1: Data collection during the research process

3.1.1 Investigation of Research Area

Initially, the project started with an investigation of existing research about information interaction, smart glasses, the operations and performance measures within a DC. Furthermore an AR themed workshop was attended where smart glasses where piloted. The aim was to achieve an understanding of different operations and the most important performance measures essential to evaluate the usage of smart glasses for the DC environment. This step resulted in the theoretical framework, which was used to support the reasoning in the analysis. The investigation consisted of three research areas. These are information interaction methods, performance measures in a DC and smart glasses effect on the performance measures. To ensure correctness of the information conducted the work of several researchers was examined for each research area.

3.1.2 Mapping of DC Processes

The next step was a mapping of the current processes at Volvo LS's DC in Eskilstuna and some of the processes at Volvo LS's CDC in Gent. The information was collected through observations and discussions with personnel in the DCs. Thereafter, the gathered information compiled and visualized in a flow chart, one for each DC. Flowcharts are used to visualize and provide a common ground for how work gets done within the organization (Damelio, 1996). This method was used to gain a general understanding of the flows in the DCs. The flowcharts provided a good overview of the current situation in both of the DCs.

To have the right support for the next step, process charts were used to visualize each of the processes in more detail. A process chart presents a screenshot of every step in a given process graphically, to ensure that everyone can understand the chart (American Society of Mechanical Engineers, 1947). The process charts brought a needed level of detail so existing information in the system was identified for the steps. While the flowcharts provided an understanding of the flows in both of the DCs the process charts was used as an input to the analysis.

To ensure that the information used for the mapping was consistent with the processes in the DC, the mapping was verified twice. The first time during the visit at Eskilstuna DC, the authors presented an initial draft over the mapping of each step for the general manager and two experienced blue collar workers. This draft could then be revised to match the processes. Later when the information types were clearly stated for each process step, the mapped information based on experience was verified for each process step. This verification was done through a Skype meeting with representatives from the DC. After the Skype meeting final changes was made in accordance with the discussion during the meeting.

3.1.3 Investigation of Potentials

After the mapping of the current processes was done, the assessments of the potential of smart glasses were analyzed. Through qualitative reasoning, the analysis focused on answering the second research question of what information that could be beneficial to communicate with smart glasses. First with regards to smart glasses as a substitute for current technology and then as a means of being able to add additional information in current processes. Lastly, problems and ideas raised by Volvo employees were used to explore additional potential of using smart glasses to change processes into more efficient ones.

All of the identified potentials were summarized and with the help of the steering committee it was reviewed to identify overseen possibilities and gaps in the reasoning. This meeting with the steering committee was held over Skype and the used presentation was sent to the participants for review. This step reduced the suggested potentials down to six. Those six were investigated in more detail before, in a similar manner again, narrowing it down to two potentials which through reasoning were believed to hold most value for Volvo LS. The value of the two remaining potentials was lastly quantified through estimations and additional data gathering. The additional data consisted of a second visit to Eskilstuna DC to make a time study and furthermore collection of present and historical data.

3.2 Literature Study

To gain an up-to-date understanding of the topics and previous research, a narrative literature study was conducted and compiled in the theoretical framework. As described by Bryman and Bell (2015), a narrative type of literature search is a more suitable and time effective method for qualitative studies compared to using a systematic method. Initially, a wide search was made to identify central topics, keywords and to facilitate the development of scope and aim. Thereafter, further search was made within the topics considered relevant and the most essential information collected and described in the theoretical framework chapter.

The three main areas that have been studied include information interaction methods, warehouse operations and distribution centers performance measures, and smart glasses effect on the performance measures. While smart glasses are a relatively modern topic in quick development, warehouse operations is a much more mature research area. This has been reflected upon within the literature study by focusing on more recent research about smart glasses while information for the other areas was gathered through various articles but also educational books.

To find relevant papers, search engines Summon and Google Scholar have been used with different combinations of the keywords: augmented reality, distribution center, AR, mixed reality, logistics, warehouse, design, pick by vision, pick by voice, order picking, process mapping, supply chain, flexibility, ergonomic, quality, productivity and performance measurements.

3.3 Empirical Data

Empirical data for the thesis has been collected through four different ways including, interviews, observations, workshop participation and on-site observations. The method for each is explained in the following sections.

3.3.1 Interviews

For a qualitative study there are mainly two approaches suitable for an interview, unstructured interviews and semi-structured interviews (Bryman & Bell, 2003). This is because it gives the interviewees the opportunity to freely express opinions, ideas and perspectives. At the same time the interviewers are able to ask additional questions if something of interest is brought up by the interviewee. During all of the held interviews, a semi-structured approach was used where an interview guide helped keeping the participant’s focus on the topics investigated. Furthermore, after the interview some of the interviewees were contacted to gain needed clarification, complementation or verification of given statements.

To ensure that the experience based information included in the analysis corresponded to the information that was used and existed in Eskilstuna DC an interview with representatives from the DC was held. The interview was conducted with the DC manager, a production manager and a warehouse worker present. The interview was held the 27th of March 2017 over Skype and a presentation was used to communicate the information to the interviewees. The presentation included a presentation of smart glasses with a sample of how visualizations could look, followed by a presentation of the interviewers and the thesis project. Then the aim of the interview was presented. The processes was discussed one by one and to facilitate a good understanding of the environment discussed the mapping of the Eskilstuna DC processes was used. Before the interview a list of possible experience based information was compiled from literature (Section 2.1.1) and from observations in the DC (Section 3.3.2; Section 4.1.1). This was done to make the process faster and to provide examples to the interviewees. The list was after the interview complemented with additional information gained through the interview.

Two interviews were held with Volvo employees as a part of the data collection process. The first interview was held with an IT manager at the IT manager's office the 2nd of May 2017. The interview concerned both historical data for Eskilstuna DC and the new sorting solution Pick & Go that Volvo LS are piloting. During the interview some questions were asked and clarifications were made regarding given quality figures. The second interview was held the 2nd of May over Skype with the HR manager for Eskilstuna DC providing figures regarding costs and absence for the DC. Both of the interviews were semi-structured with some predetermined questions that the interviewees could answer freely. Follow up questions were asked both during the interviews and later by email regarding both areas. Furthermore, access to records of historical discrepancy data was gained following the interviews.

3.3.2 Observations

To collect data for mapping and understanding the operations in Eskilstuna DC and Gent CDC, a method of participant observation was used. First during a two days visit to Eskilstuna, 21th of February 2017. Thereafter during a three day visit to Gent 20th of Mars 2017. Lastly, during a second visit to Eskilstuna DC, 10th of May 2017. As described by Bryman and Bell (2015), participant observation allows the researchers to find unexpected issues as well as see situations through others' perspectives and their actual behavior. Furthermore, the method is relatively easy to use for the given case, considering a limited time span and that the operations are carried out in a very well specified manner each day. First the visit in Eskilstuna DC is described followed by the visit in Gent CDC and then the second visit in Eskilstuna DC.

During the first in Eskilstuna DC, the warehouse general manager and various DC personnel guided the authors who observed the warehouse operations meanwhile asking questions freely. The first day by simply following the product flow, starting from the point where products arrived to the warehouse, to when they left the warehouse. After compiling the observations from the first day, an initial process map was made, which was during the second day presented to the general manager and two experienced blue collar workers. After verifying the findings and identifying the remaining information gaps, the authors once again observed the operations by following the material flow to fill those gaps.

The visit in Gent CDC was guided by a Process & IT manager and various warehouse employees. During the tours the authors observed the warehouse operations, some of them in more detail than others, while asking questions to both guides and operators. The processes investigated were those which were not observed or conducted in Eskilstuna DC, including the returns, quality, dangerous goods and voice picking process. Each process was carefully followed and documented to enable the following mapping of the process. Furthermore, the names of the employees were saved to enable the authors to send more questions in case the process steps were unclear.

3.3.3 Time Study

To collect data for the last analysis step, a time study was conducted to estimate how much time that is spent on sortation after the picking process. It was conducted through videotaping operators working in the process, which allowed the time consumption of sortation to be extracted. This based on definitions made for the boundaries of the activity. Two different packing stations were studied, the first where small parts are sorted and packed, and the other where medium sized parts are handled. There is one more packing station in Eskilstuna DC where large items are packed, however, no sortation is conducted here. The sortation time was calculated per order line, because each order line drives time consumption when it needs to be sorted to the corresponding order. In total, the sortation of 140 order lines and 62 orders was studied. To gain a more representative process time, four different operators were studied, all of them with significant experience of the process. However the operator's awareness of being studied has most likely affected the result (Hawthorne studies, 2014). This effect has not been taken into account, since what was searched for was a rough estimation of the minimum time spent on sorting. In between each recorded sortation of a picking batch, trials were made to see if the cardboard boxes in which all orders were packed in could be carried on the forklifts used today in the picking process. This was done by placing all the cardboard boxes derived from one picking batch on the respective forklift’s load area and note if it fit or not.

3.3.4 Workshop

To gain initial understanding and user experience of smart glasses, both authors participated in a workshop with the theme Pick-by-AR. The workshop was created within the frame of two other research projects conducted at Chalmers University of Technology, both touching upon picking with smart glasses for kitting in assembly areas. The workshop was set up at the Schenker DB’s warehouse in Landvetter at 14th of February 2017. The workshop was led by representatives from Chalmers University of Technology, Schenker DB and Virtual Manufacturing. Participants in the workshop were industry representatives from over ten different organizations.

During the Pick-by-AR workshop, the participants themselves got to experience picking an order in a laboratory environment that was set up. Approximately, the environment consisted of about 40 distinct product bins arranged in three bays, each being three-level high. During the workshop, both a smart glass solution using Google glass as well as an interactive smart glass solution using Microsoft Hololens was tried out by the participants. After using the technology, the about 30 participants joined together to discuss the possibilities, drawbacks and challenges still to be solved. This provided insight to several different perspectives on smart glasses and its applications, from different companies but also different areas such as production, assembly, warehousing and consulting.

3.4 Source Credibility

The opinions regarding what aspects and criteria’s that should be analysed to ensure the quality of qualitative studies differ between researchers (Sinkovics et al., 2008). Hence, no general way to enhance the quality of a qualitative study exist (Rolfe, 2006). However, Ahrne and Svensson (2011) stress the importance for qualitative studies to prove trustworthiness and Bryman and Bell (2015) highlight the importance of taking ethics into consideration.

3.4.1 Trustworthiness

The concept of trustworthiness consists of four dimensions: credibility, transferability, dependability and conformability (Bryman & Bell, 2003). These four criteria's together indicate the trustworthiness of the study.

The credibility of a study relates to the compliance of the data used within the study and the reality. There are two different types of data used: primary data which is data collected only for this study and secondary data which is already available and not gathered for the specific study (Skärvad & Lundahl, 2016). By determining the credibility of the references used the secondary data used in the study can be evaluated. The references used to formulate the theoretical framework are published in known journals or by well-established publishers so they are assumed to be credible. To improve the credibility of the primary data collected several different methods or data types, were used. This is called triangulation and strengthens the credibility of the conclusion (Wilson, 2006; Bryman & Bell, 2003). The primary data collection described in earlier subchapters consisted of observations of the DCs, interviews with partners and a workshop discussion with practitioners. The data collected with the different methods is compared to each other and also to literature to ensure the thesis credibility (Figure 3.2). The different methods used were performed with different participators and in different settings. Hence, several different perspectives that pointed towards the same conclusion ensured credibility. However, regarding credibility there is a risk that impressions made during the literature review, observations or interviews reflected the results of the study.

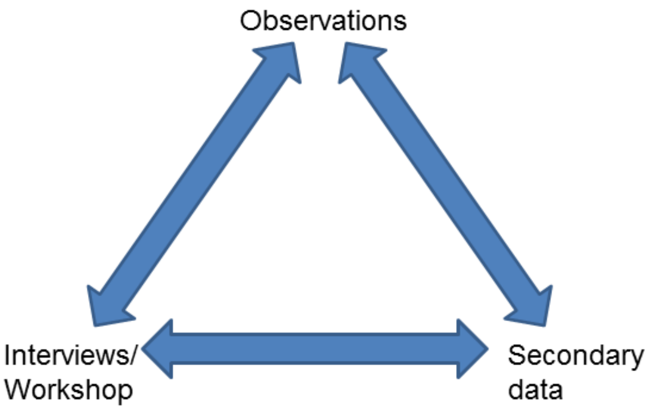

Figure 3.2: Triangulation within the study

Transferability address whether the result of the study is applicable for other contexts. According to Bryman and Bell (2003) are qualitative studies often related to a specific case and context. The thesis is connected to the specific case in the Eskilstuna DC as well as the DCD in Gent. Since the study was conducted in distribution centers for spare parts in the automotive industry, the transferability to different contexts and industries is questioned. Consequently, it is unlikely that the result can be directly transferred to a context that differs from the one in the DC. However the investigation of the experiences based information and the possibility to use smart glasses to display this information can be of use for managers. Moreover, the references used in the theoretical framework consist of multiple independent studies. According to Yin (2009) can case studies have issues with generalization. Therefore is the compilation of smart glasses effect on common performance measures, from multiple sources that point towards the same conclusion, a contribution to future research.

Dependability concerns the replicability of the study. To be able to redo the study and still get the same result it is important to document all the steps in the process (Bryman & Bell, 2003). The study is highly dependent on few individuals' perspective since, the observations were performed during a very limited time and discussions were held with a limited amount of people. Because of this the study is affected by these individuals perspective of the operations. To avoid this as much as possible the aim of the study has been explained to everyone involved and the questions asked has been as concrete as possible. Bryman and Bell (2003) suggests researchers to use an auditing approach and ensure complete records. However, instead of publish all of the fieldwork notes and interview transcripts the gathered information has been validated. The interviews were validated by sending the notes for approval by the interviewee, the observations by a reviewing with managers and operators at site and the workshop results by comparing notes with the responsible PhD student. Moreover, since the investigated technology is developing the conditions for a study will soon have changed and with more information regarding the technology development if may be impossible to come up with the same result.

Conformability is the question about how personal values and opinions affected the conclusions of a study (Bryman & Bell, 2003). Data gathered through observations and interviews consists of personal and judgmental opinions. The interviewee is easily influenced by the researcher's own values (Gillham, 2007) and the observations are vulnerable to the same influences. As both the authors and thesis supervisors have an interest in technology and a positive attitude towards the investigated area, the conformability could be criticized. However, with that in mind, all major results from observations, interviews and workshop has been documented in conjunction to the event and afterward discussed to ensure that a common view has been received. In doubt, the authors have reached out to respondents or people working in the observed processes to verify that a correct view has been received.

3.4.2 Ethical considerations

To evaluate ethical principles Bryman (2012) describes four areas of ethical principles: harm to participants, lack of informed consent, invasion of privacy and deception. During the thesis the researches have been aware of the ethical implications acted to prevent ethical violation. To avoid ethical issues have interviewees and observed individuals been informed about the purpose of the study and how the results from interviews and observations will be used. The purpose has been to see the potentials for the future and not to evaluate the current performance. Because of those individuals has not been afraid to share their thoughts. Furthermore, all collected information has been validated to ensure that information is correctly understood and interpreted. This is to provide the individual the possibility to review the information before it is published. Beside that will all participants be kept anonymous and no names will be published to further protect the individual's integrity.

4 EMPERICAL DATA

The empirical data present the data gathered for the thesis. Firstly, the data collected at Eskilstuna DC is introduced with an explanation of its DC processes in chapter 4.1. This is followed by a presentation of performance data gathered at the DC. Secondly, in chapter 4.2 Gent CDC is introduced together with the additional processes that are carried out there. The voice technology used at Gent CDC as the current best practice for Volvo LS is presented, as well as ongoing pilot projects relatable to the thesis. Lastly, information gained from an AR workshop is presented, which was used to gain an initial understanding of smart glasses technology during the thesis.

The data of the DC processes and the voice system is gathered from on-site observations. To facilitate the reader's understanding, each presented DC process is provided together with a flowchart overview. The descriptions related to each process step in the flowchart through enumeration. All performance data presented of Eskilstuna DC was gathered during the concluding part of the thesis and analysis, through performance records, interviews and a time study.

4.1 Eskilstuna Distribution Center

The Eskilstuna DC serves as a support distribution center, with the aim of fulfilling day orders for customers, dealers in the Nordic region. This means that the DC is supposed to cover unusual high end-consumer demand or demand for products not stored at the dealers with same-day delivery. Items ordered by dealers can include items from all of the following Volvo group brands: Volvo Trucks, Volvo Construction Equipment, Volvo Penta, Renault Trucks and Volvo Buses. The items held are in general too capital intensive, large or infrequently ordered for keeping stock at individual dealers. The day orders are expected to be fulfilled the same day if ordered before the cut-off time, which is about one hour ahead of shipment time. To keep control of and improve the DC performance, records are made on KPIs concerning productivity, quality and ergonomics which is also communicated towards the operators. These KPIs include for example order lines handled per labor hour, number of customer complaints received and sick leave percentage. The flexibility dimension is however not measured.

There are two main flows in Eskilstuna DC (Figure 4.1), one inbound process and one outbound. For the inbound process Eskilstuna DC receives daily internal deliveries from the central distribution center (CDC) in Gent. The arriving truck contains the products needed to refill the stock levels at Eskilstuna DC. What items to be refilled are decided centrally and the orders are generated automatically. For the outbound process the customers place orders that are picked, packed and shipped the same day. The customers consist mainly of external dealers but also some internal Volvo dealers.

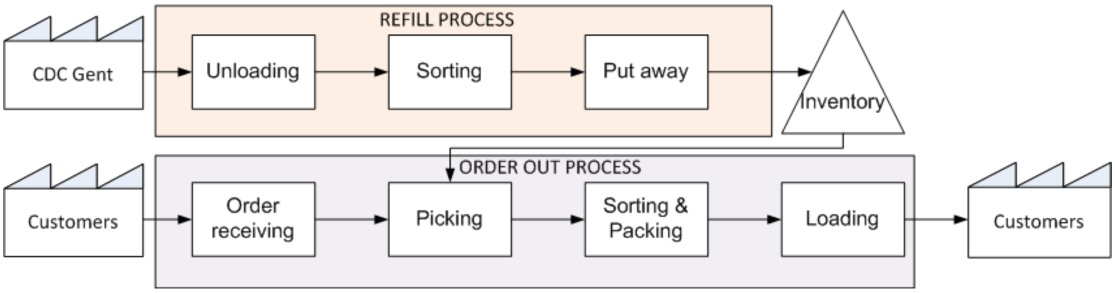

Figure 4.1: An overview of the flows in Eskilstuna

All processes in the DC are manual, to ease the work, operators have a scanner that can support them in the tasks. With the scanner operators are able to receive instructions regarding SKU positions, quantities and destinations. Furthermore, operators use the scanner to confirm items and positions with the WMS. The scanners used in the DC are so called ring scanners meaning that the operators have a terminal attached to the forklift and a scanning device on their finger. This allows the operators to work with both hands and both scan and grab in the same movement. However, the scanners can still be used like a regular scanner if there is a reason for it. To store temporary information the DC use temporary barcodes so called ESK-labels. The products in the DC are stored in storage racks with multiple storage levels. The products have dedicated storage spots within one of the more than six zones. The zones divide products primarily according to size and weight characteristics which mean that different forklifts are used for different zones. The zones are furthermore to some extent also divided based on what Volvo Group brand the product belongs to and how frequent they are ordered, but in a rather arbitrary and undefined manner. A synchronized zoning strategy is used in the Eskilstuna DC which means that while an operator handles part of a customer order in one zone, another set of order lines from the same order could simultaneously be handled in another zone.

4.1.1 Information in the Processes at Eskilstuna DC

In this subchapter, the process charts of all processes conducted for the main flow of material are presented. Within the processes of Eskilstuna, different information was observed to be used by the operators, which can be seen below the name of each process step in the flow charts. These were divided into three different types of information, received information, transmitted information and experience based information. Received information represents all information that is used in the operations, which is provided to the user at that time through any information communication device from the WMS. This type of information is in the process flow charts represented by a yellow color. The second type of information is transmitted information, represented by a red color. This information type refers to the information that an operator in some way uploads to the system, for example confirmation that a picker has reached the right product shelf. Lastly, the third type of information is experience-based information, which is information that operators need or would have use of having, but is currently only provided through the operator's own knowledge or experience. Worth noting is that there is more information used in the warehouse other than what is included in this chapter. The selection is based on what authors and practitioners believed to be needed or useful to have for operators, which excludes some very basic information. An example of such information is from where and in what order new picking lists should be retrieved once a picking round has been completed. It is also based on the assumption that the operator has a basic knowledge of how activities should be performed, for example how heavy items should be lifted in an ergonomically safe way or how items should be handled if they are fragile. Furthermore, all observations are of an operator performing a specific process. The observed process steps have afterwards been revised with information about how the process is supposed to be performed. Meaning that the variety of how different operators perform specific tasks has not been observed or considered.

Unloading. As the very first process in the flow of materials within Eskilstuna DC, the unloading process ensures that incoming products from Gent CDC are unloaded (Figure 4.2). The freight is unloaded from the truck and put in a designated waiting area (2). No significant information exchange was observed in this process.

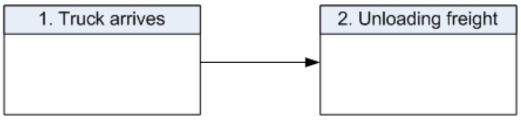

Figure 4.2: Unloading

Sorting. After staging all pallets in the waiting area the next process is to unpack and sort the parts (Figure 4.3). Pallets are collected one by one (1), opened and scanned to receive information regarding what SKUs in what quantity that are contained in the pallet (2). When the pallet barcode is scanned SKU labels for all of the products registered for that pallet is printed on a long slip (3). When a product is picked out of the pallet by an operator (4), there are several considerations taken into account to decide if the person needs to handle the product in a special way. The identified parameters are if the product is heavy, fragile or if the product is sharp. The judgment about these parameters is done by the operator and will affect the ergonomics for the worker. After or simultaneously as a SKU is picked, the quality is checked (5), it is cleared if the product and packaging is in an acceptable condition. The operator also need to search for and locate the correct SKU label, this can be a time consuming activity since the slip with SKU labels can be long, when the label is found it is scanned (6). This is an unnecessary process step that both the operators and the general manager raise concerns about.

To decide if it is the right product, the operator controls that the part number on the SKU label matches with the part number on the product. The operator can to some extent furthermore base the decision on experience of what the product should look like using the product name written on the SKU label. Whether the product is in an acceptable condition is solely decided by experience of how acceptable products or packaging should look like. The quantity of the product is checked by matching it with the quantity displayed on the scanner (7), the operator confirms the quantity and attach the SKU label on of the product (8). Some items are handled in multiples, which means that the quantity of five for a certain product may refer to five cases of ten pieces each or one case holding five pieces. Information regarding multiples is not communicated to the operator but instead based on experience. When the quantity is confirmed information about which zone it is to be put away into is presented and the product is thereafter put into a temporary position waiting to go through the putaway process (9). Information regarding that the products are temporary stored in a container is transmitted by scanning an ESK label which is connected to that temporary position (10).

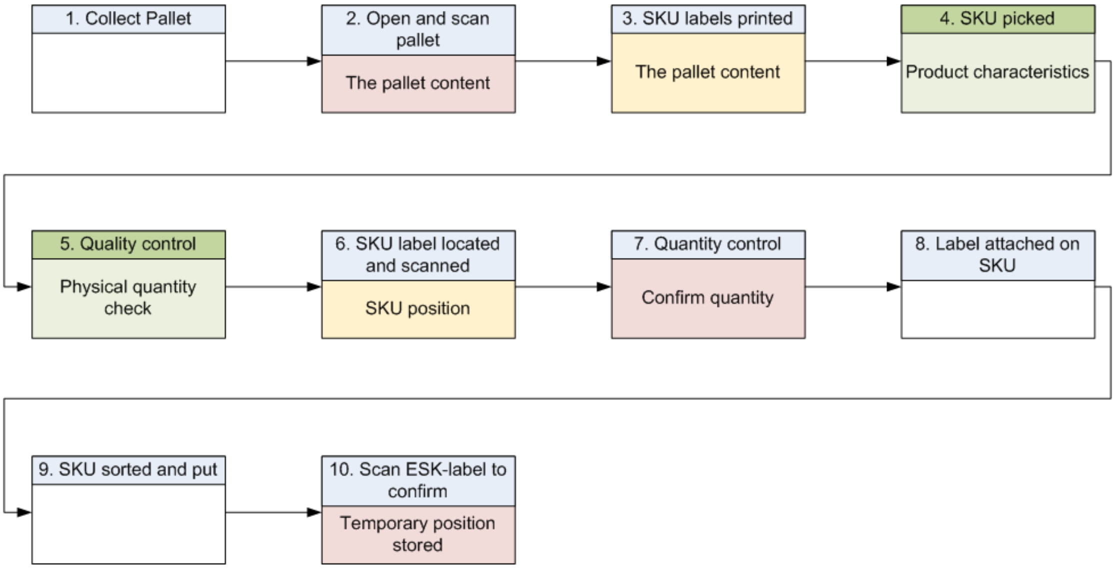

Figure 4.3: Sorting

Putaway. The putaway process starts with an operator retrieving a container that temporarily holds products designated to be moved into storage in a certain zone of the DC (Figure 4.4). The ESK-label belonging to the container is scanned to retrieve information into the operator's scanner regarding what items are stored in the container, in what quantity and what shelf positions they belong to (1). The scanner will then display this information (2), SKU by SKU in a list arranged according to the sequence that they appear in the warehouse, assuming that the operator follows a predefined serpentine path in that zone. The operator will then, based on the information received regarding SKU position transport to the designated shelf position (3). This is conducted through following predefined routes through the inventory zone. However, operators can use their experience to gain transport information, which mean that they are able to adjust their transport by knowing how far it is until next stop, if there are any passages with risk of accidents or if another path should be taken due to congestion.

Well at the storage location of a SKU, the operator will place the items into storage and confirm in the scanner that the right quantity has been put in (4). While putting the items into storage, once again does the product characteristics need to be considered, meaning if there are needs for special handling due to risk for injuries on the operator or risk for damage to the product (5). Lastly, the operator scans a shelf barcode belonging to the specific shelf position, which transmits and controls that the right shelf position has been used (6). After that, the process is either finished, or the operator will be routed to a new SKU shelf position for the next item to be put away (7). This is the last activity that ends the process of moving the products from unloading to the inventory.

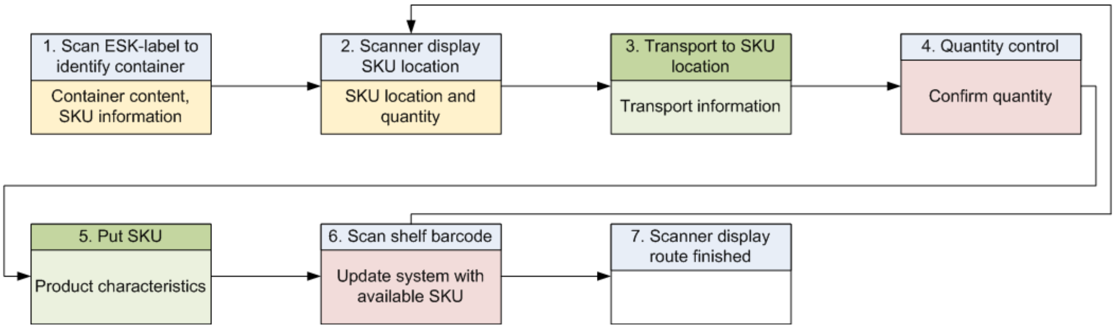

Figure 4.4: Putaway

Order receiving. The first part in the order out process is the order receiving function (Figure 4.5). When customers in the region covered by Eskilstuna DC create orders for spare parts, they are registered and received by the DC (1). The order lines within each order are split up according to which zone they are stored in (2). Thereafter, the zone leader uses a computer to monitor incoming orders and zone workload distribution in the zone (3). Based on guidelines of how many orders or order lines a picking list should contain known truck departures and given workload information, the zone leader decides when to create a new batch to be picked (4). The batch information is printed and contains information about all order lines to be picked (5), their respective quantities and positions as well as the same information separated order by order. The paper copies are put into stacks for pickers to retrieve prioritized so the earliest delivery times are picked first (6).

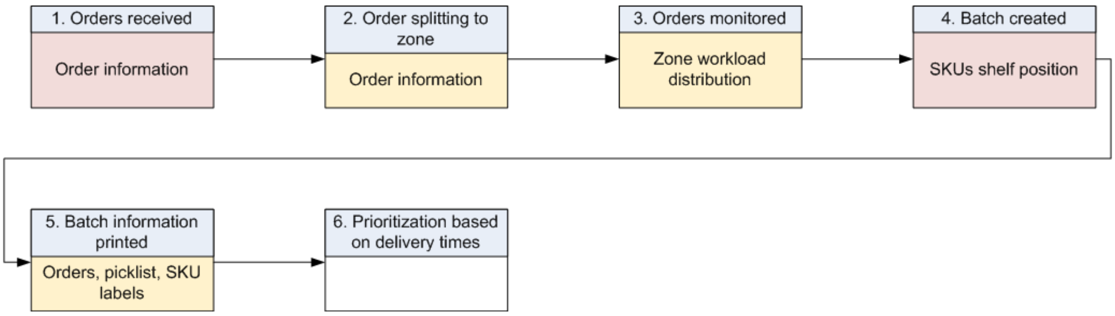

Figure 4.5: Order Receiving

Picking. Because the inventory zones are divided based on what type of forklift is used within that specific zone, the picking processes starts with an operator using a forklift designated for the area to be picked (Figure 4.6). A container to pick items into and a picking list will be retrieved by the operator (1). When the operator uses the carried scanner to scan a barcode on the picklist, the picking batch is identified and all information regarding it is retrieved, which contains all SKUs to be picked and their respective quantities and positions (2; 3). In a similar manner as in the putaway process, the location is displayed in an order that follows the SKU location order (4), provided that the operator follows a predefined serpentine pick path through the zone. When transporting to the SKU location (5), the operator gains transport information from experience. That means information regarding the warehouse layout to know the path to follow, how far it is until next position and if there are areas which usually are congested or dangerous areas. Through that information, it is possible for the operator to figure out how fast to travel and when to slow down to start searching for the specific shelf position.

Well at the shelf position to pick from, the operator will scan the shelf barcode (6) to confirm that the right position has been found. Then the scanner will display SKU quantity to be picked (7). The operator will then pick the SKU (8) and place a SKU label on the SKU (9). Thereafter the operator will put the SKU into the picking container (10). The operator will here use experience to decide if there is a need for any type of special handling (8; 10). In this case, the identified dimensions are if the products weight or shape has a significant effect to ergonomics, if there is a risk of damaging the product in the handling or if the product is handled in picking multiples. The SKU label that is placed on the SKU (9) is put on the last product piece of each order line, this to facilitate the packing and sorting process that follows. Before getting information about the next position, the operator needs to confirm that the right quantity was picked (11) by pressing a key on the scanner. When all SKUs are picked, the scanner will display that the route is finished (12). The operator will transport to the packing area (13) and deliver the picking container (14). By the packing stations there are more people moving compared to the inventory zones, which make the last transport most dangerous.

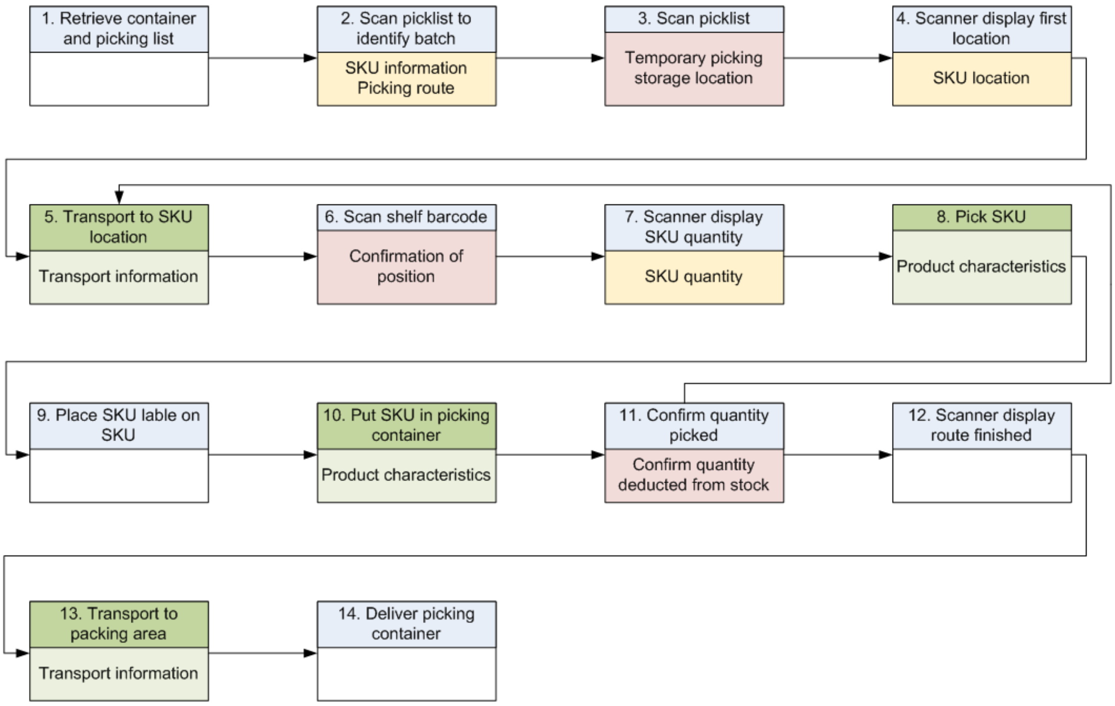

Figure 4.6: Picking

Sorting & Packing. Once the picking process is complete and all items have been brought to the packing station, the batch is ready to be sorted into individual orders and get packed (Figure 4.7). From the picking list, an operator chooses an order to pack, identifies what products that belong to that specific order and collects them (1; 2). Once again will the products be picked and the operator will need to consider if there is a risk of damage or injury. Furthermore, the quantity is controlled so that it truly matches what has been ordered. Worth noting here is that a customer might have ordered SKUs from two or more zones, which then will be sent as separate shipments. The SKU labels and a new ESK-label is scanned to system-wise put the items into a temporary position (3), which physically represents the box in which the order will be packed. The packer will use experience, visual estimates or measuring tape to decide which cardboard box that is suitable to ship all products in (4). To be able to identify the shipment an ESK-label is placed on the box (5). The ESK-label and box barcode is scanned to transmit box measurements which are needed to later on print a shipping slip (6).

Once the operator has everything ready, the SKUs are put into the box (7). Because the package will be put on a truck and shipped a potentially long distance afterwards, it is essential to pay attention to how the items are handled in this stage. The operators need to assess the product characteristics and how they should be packed. This includes a decision about placement of the product, in what sequence and orientation products should be packed, but also if filling material should be used and in that case how much of which filling material (8). To lower the DC costs a production manager explain that they should start displaying the cost of the material that are being used. Once everything is packed, the ESK-label which can be said to contain all information about the shipment is scanned together with the barcode of the packing stations printer (9). This step allows for the shipping slip to be printed (10), which is added on the box and the whole package is put into a destination-sorted waiting area (11; 12).

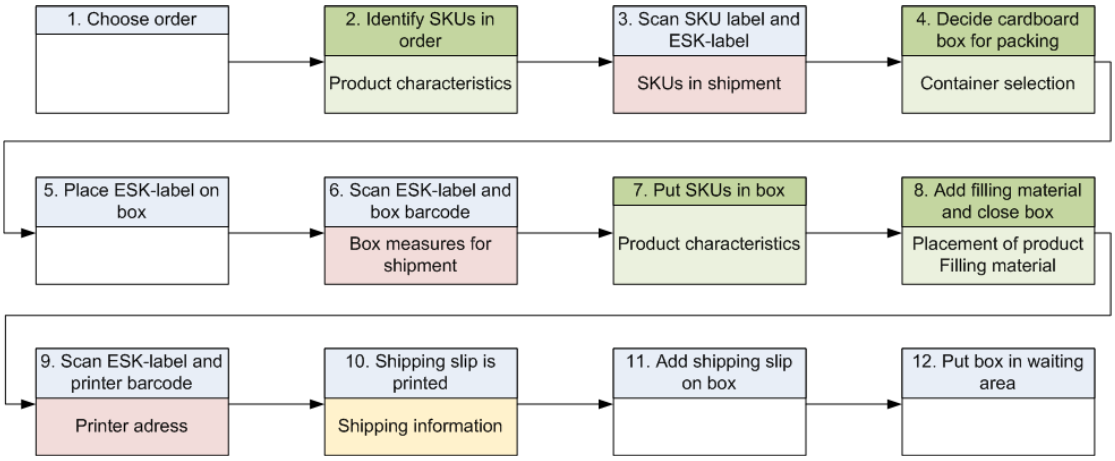

Figure 4.7: Sorting & Packing

Loading. Eskilstuna DC has fixed times for when packages are to be collected (Figure 4.8). When the time is approaching one of the departures, the packing station personnel will identify the shipping containers, containing all packages for next departure (1). The containers are thereafter transported to the outbound gate and then the outbound area (2; 3). From there, a forklift operator will load them into the truck (4). To ensure that everything fits and can be transported with minimal risk for damage, the operator will through experience decide how to pack it into the truck. While doing so, the operator will need to consider in what sequence the containers are to be unloaded, their orientation and how they should be stacked so that no items are crushed. One problematic factor is that in the beginning of the day the volumes that should be shipped are unknown, which results in difficulties associated with the ability to plan the size of the trailers. When everything is loaded the operator confirms the completion of the loading to the driver (5). This is the last activity before the parts leave the DC. The director for the division process and IT was considering how the business could improve the packing and loading to avoid shipping unnecessary air.

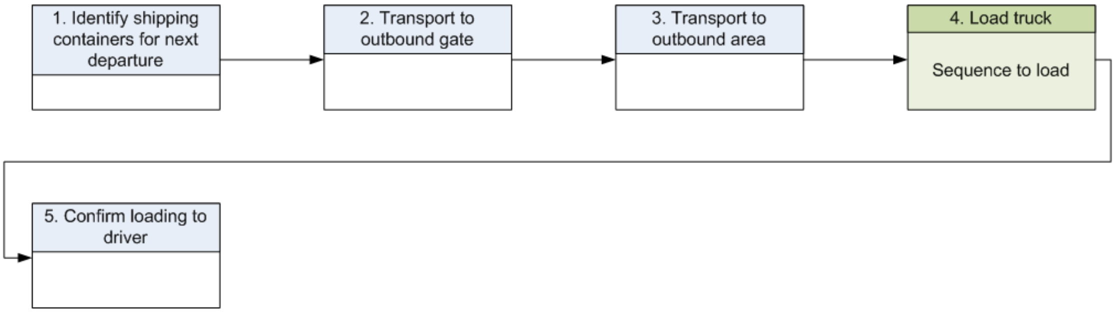

Figure 4.8: Loading

4.1.2 Experience Based Information within the Processes

The experience based information used within each of the processes was developed from literature (Section 2.1.1) and observation in the DC (Section 4.1.1). This information was compiled and presented for representatives from the Eskilstuna DC. During that meeting some additional types of experienced based information was identified, those information types will be further presented in this chapter.

For product characteristics in sorting, putaway, picking, and sorting and packing was frail surface added (Figure 4.9; Figure 4.10; Figure 4.11; Figure 4.12). The operators in the processes can increase the quality in the process if they are aware that the surface of the part is sensitive for example for scratches. Then regarding putaway and picking low frequent and common mistakes was added (Figure 4.10; Figure 4.11). Low frequent is of importance since the operators are less likely to remember characteristics of parts that are handled seldom. Common mistakes are important to include due to the fact that the mistakes the operator or other operators have made in the past are normally more common to redo. For loading no extra dimension was identified but extra emphasize were put on the sequence that the goods needs to be loaded (Figure 4.12), both to ensure that an easy unloading could be performed and to ensure that all goods fit in the trailer.

Sorting

- Product characteristics
  - Sharp
  - Heavy
  - Fragile
  - Product multiple
  - Frail surface

Figure 4.9: Experience based information in sorting

Put away

- Product characteristics
  - Sharp
  - Heavy
  - Fragile
  - Product multiple
  - Low frequent
  - Frail surface
  - Common mistakes
- Transport
  - Traveling distance
  - DC layout
  - Congestion
  - Traveling speed
  - Dangerous zones

Figure 4.10: Experience based information in putaway

Picking

- Product characteristics
  - Sharp
  - Heavy
  - Fragile
  - Product multiple
  - Low frequent
  - Frail surface
  - Common mistakes
- Transport
  - Traveling distance
  - DC layout
  - Congestion
  - Traveling speed
  - Dangerous zones

Figure 4.11: Experience based information in picking

Sorting & Packing

- Product characteristics
  - Sharp
  - Heavy
  - Fragile
  - Product multiple
  - Frail surface

- Packaging instructions
  - Placement in shipping container
  - Container selection
  - Product placement
  - Filling material

Figure 4.12: Experience based information in sorting and packing

Loading

- Loading instructions
  - Loading sequence
  - Stacking
  - Orientation

Figure 4.13: Experience based information in loading

4.1.3 Quality Performance

To track the quality of shipments sent from Eskilstuna DC, data is collected from customer complaints made on said shipments. Every complaint is investigated, for example through checking physical inventory compared to inventory levels according to the WMS. When a decision is made that the complaint is correct, the time and type of error will be stored. These errors are called discrepancies. The types of discrepancies that are tracked include: under deliver, over delivery, delivery of wrong part and delivery of damaged part (Table 4.1). Over delivery and under delivery is reported when a customer has received the ordered SKU but in too many respectively to few pieces. Wrong part discrepancy is reported when the customer receives a part that does not correspond to the ordered item. Lastly, a discrepancy of damaged part will be reported if the right product has been received but the customer refuses to accept the product due to issues with its condition. Every discrepancy case that occurs will only be reported as one type for every order line that is faulty.

In addition to the discrepancies, data is also collected for so called nilpicks (Table 4.1). Nilpicks are basically the result of deviations between physical inventory and inventory data. They occur when a picker is directed to a SKU location to pick X amount of products for an order but only X-1 or less products remaining in the location. The high number of nilpicks is explained by the fact that the DC recently changed from being a CDC for one Volvo brand into being a support DC for several Volvo brands. That transformation initiated movement of almost all stock resulting in less inventory control. During 2016, the number has steadily decreased towards a rate of about 700 per year.

Table 4.1: Deviations in Eskilstuna DC during 2016

2016 Data Eskilstuna DC	Total reported	Percent of total Discrepancies
Orderlines	664 462	-
Underdelivery	-	59.6%
Overdelivery	-	2.8%
Wrong part	-	24.0%
Damaged part	-	13.6%
Nilpicks	1335	-

Because the discrepancies vary in type and impact, it is hard to quantify the cost of a discrepancy, for example it may sometimes be required that a new part is sent with express delivery while other times it can be shipped with the next scheduled shipment. Because of the difficulty of calculating a general discrepancy cost and the fact that Eskilstuna DC is a relatively new support DC, there is no calculation for that cost. However, over 3000 discrepancies in 2016 were logged to calculate an average discrepancy cost for orders shipped from Gent CDC within one specific Volvo brand. This cost includes both the cost of handling the complaint order line as well as the crediting of goods value. Using that average discrepancy cost, total cost for Eskilstuna DC's discrepancies amount to about 580 000 SEK. In addition to the discrepancy cost, there is also a scrapping cost for the products that needs to be thrown away because of damages. The total product value for all products that broke while being handled in the DC processes in 2016 was about 3000 SEK.

4.1.4 Ergonomics Performance

In Eskilstuna there are 63 employees working in the distribution center, rotating between different processes over time. The work is recognized as physically demanding and repetitive, with a resulting risk for strain injuries. When employees need to be absent from scheduled working hours, records of the absence and its' main reason are taken. From the records of 2016, 12 % out of all the time that employees were absent were reported to be because of strain injuries or more specifically 'pain in the neck, back, shoulders causing mobility problems'. While employees are away from work in Sweden, Volvo pays 80% of employee cost for a maximum of 13 days, starting the day after the day that the illness is reported. This day is called the qualifying day of sickness and goes without payment. Therefore, estimation is made that only about 75% of total absent hours are paid by Volvo. When the workload is too high to manage with remaining workforce, a staffing agency is used to balance workload in the short term. With consideration to both the agency staff and employee costs, the total cost during 2016 for employee absence due to strain injuries corresponds to about 287 000 SEK.

4.1.5 Performance in the Sortation Process

The sorting and packing process involves receiving batches products from the picking process and sorting them into separate orders to finally pack each order in separate packages and move it to the loading process (Section 4.1.1). Whether or not all final order packages from one batch potentially could be carried on the forklift used in the picking process was tested for both the packing area of small as well as medium parts. The test was performed by physically placing the packages produced by a total of 10 different picking batches on the forklift used. For the small items, it seems that it is possible to fit the finalized packages onto the forklifts or mopeds used. Although, it might require a modifications of the larger cardboard packages used so that it can be opened on the short side thus requiring less space in the horizontal plane. In one of the trials, two of the packages needed to be placed with the short side down to properly fit on the forklift. However, for the rest of the cases it would be possible to increase the batches since many more packages could fit on the forklift or picking moped than what had been picked. For the medium size packages, the packages produced by one picking batch could not fit on the forklift in neither of the trials. To enable the cardboard boxes to fit either the batches would have to decrease or the design of the boxes would have to change so that they could stand upend.

The process sorting and packing was observed and recorded for both areas but the times in the videos were only analyzed for the area with small parts based on a decision about potential (Section 5.3.2). The two categories measured are sorting and packing. Sorting include the time a product is sorted based on customer orders and packing include the time it takes for the operator to decide, retrieve and pack the parts. This division is done to distinguish the time operators spend on sorting the parts into piles corresponding to a given customer. The time to retrieve the box with parts from the picker and the time to put away the packed cardboard boxes for shipping is excluded from the process since it is not of relevance to the project and was often affected during the time study. If the time for sorting and packing is summed up for all trials sorting takes up 14 % of the time on average. Per order line for the area for small parts the operators spend on average 5.3 seconds on sorting per order line. If looking at the total time spent on sorting with respect to the order lines that are sorted and packed in the area for small parts, the existing savings potential can be estimated. If the total time spent on sorting in the area for small parts is multiplied with the cost for an operator during an hour the yearly savings potential if sorting can be removed is estimated to 213 893 SEK.

4.2 Gent Central Distribution Center

The Gent CDC serves as a central distribution center, storing most parts sold by Volvo in the European region. The processes included in the operations of the CDC are similar to what is conducted at Eskilstuna DC (Figure 4.14). However, these operations include more elements making it more complex. Besides being larger and handling a higher number of SKUs, the CDC deals with dangerous goods, product quality inspections and receives as well as sends products to far more destinations. For the main flow of order lines in the CDC, a voice solution has been implemented. However, of all processes conducted in this flow, it is only in the picking process that pick-by-voice technology is used. The remaining processes, including other material flows are conducted similarly to what is done in Eskilstuna DC, using scanners, monitors and paper. The WMS that is used differs from the one used at Eskilstuna DC, but is planned to be changed so that the same system is used by 2020.

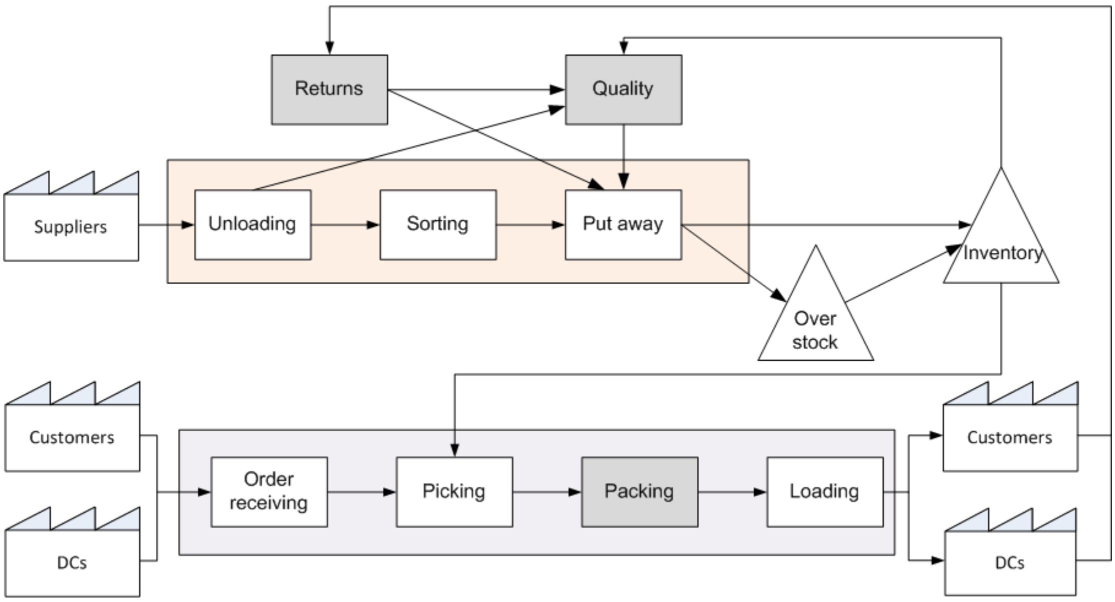

Figure 4.14: An overview of the flows in the CDC in Gent

4.2.1 Information in the Processes at Gent CDC

Return. One of the processes conducted at Gent CDC is the handling of material returns (Figure 4.15). It is to some extent also handled at Eskilstuna DC, but the process is larger and better defined in Gent CDC. There are several reasons why goods sometimes move backwards in the material flow, from dealers back to the Volvo DCs. These include for example quality dissatisfaction, buy backs of unused stock at dealer and return of parts that was wrongly ordered. Before sending the returns back to the DC, dealers need to register the return into a Volvo IT system as well as the return reason to facilitate the return process. The process itself can be said to start when a pallet of returned goods from a dealer is brought to the return station. By then, part labels for the pallet has already been prepared, which is a pile of physical labels with information that corresponds to the parts in that specific pallet. This part labels contains information of what items are to be returned, in what quantity, the monetary SKU value, the reason of return, SKU description, original packing material and lastly, an indicator if there is any historical data of quality issues with the part. The operators in the process expressed hassle about having to deal with these large piles of labels.

Once a pallet has been retrieved, together with the belonging list of part labels (1), an operator will start by taking an arbitrary part and identify its part number (2). This number is used to identify what SKU that is being handled and the matching part label from the pile of labels. Based on the description or name of the SKU, the operator will make three judgments. First if the part that has been returned is right (4) which mean identifying if the parts are the same as what the dealer registered for return. Secondly, if it is in acceptable and unused condition, meaning that the packaging and part is checked for damages (3; 5). Lastly, a judgment whether the return should be accepted or rejected (7). The concluding judgment is based on the quality reasoning that the operator makes based on the product knowledge that he or she has access to. Sometimes, the part label contains a history code which provides the operator with knowledge about previous quality problems of the SKU and further help with the judgments (6). If the return is deemed to be correct in all quality aspects, it will be accepted, resulting in a refund to the dealer. The part will then, if needed, be repacked and fitted with a new SKU label and then sorted into containers going to the putaway process (8; 13; 14). The parts put in the putaway containers are scanned so that a putaway list can be printed afterwards, allowing operators in the putaway process to know which storage locations that need to be visited (15; 16).

If a return is not accepted by the return process operator, the part will be scrapped and a reason for why it is not accepted is entered into an IT system through a desktop computer (11; 12). There are two exceptions to this normal procedure of either accepting or not accepting a return. Firstly, if the SKU has a known historical quality problem or a very low value, it will generally be accepted yet still scrapped to prevent the return from causing future quality dissatisfaction. Secondly, if the product holds a high value or is particularly hard to make a judgment for, the operator may receive help from the supervisor or a quality team with even more experience (9; 10).

The three judgments that are made by the operator about the quality of the return, meaning the identification of the part, its condition and if it should be accepted, is to a large extent based on the operator's own experience. The operator has, often through working with for example order picking for several years, an accumulated experience of how the different types of spare parts look like. However, the operator is able to gain additional information to support the judgment about the return. By using a regular computer placed close to the working station, it is possible to access SKU drawings, bill of material, extended description and record of known quality issues. This can be done in the company's systems RAPID and GLOPS. Although, it is a rather time consuming activity since it requires the operator to log in to the computer, into the IT system and to manually enter the products part number. Furthermore, for a significant amount of SKUs, the Meta data is not complete meaning that the operator may be able to only access some, if any, of the mentioned information.

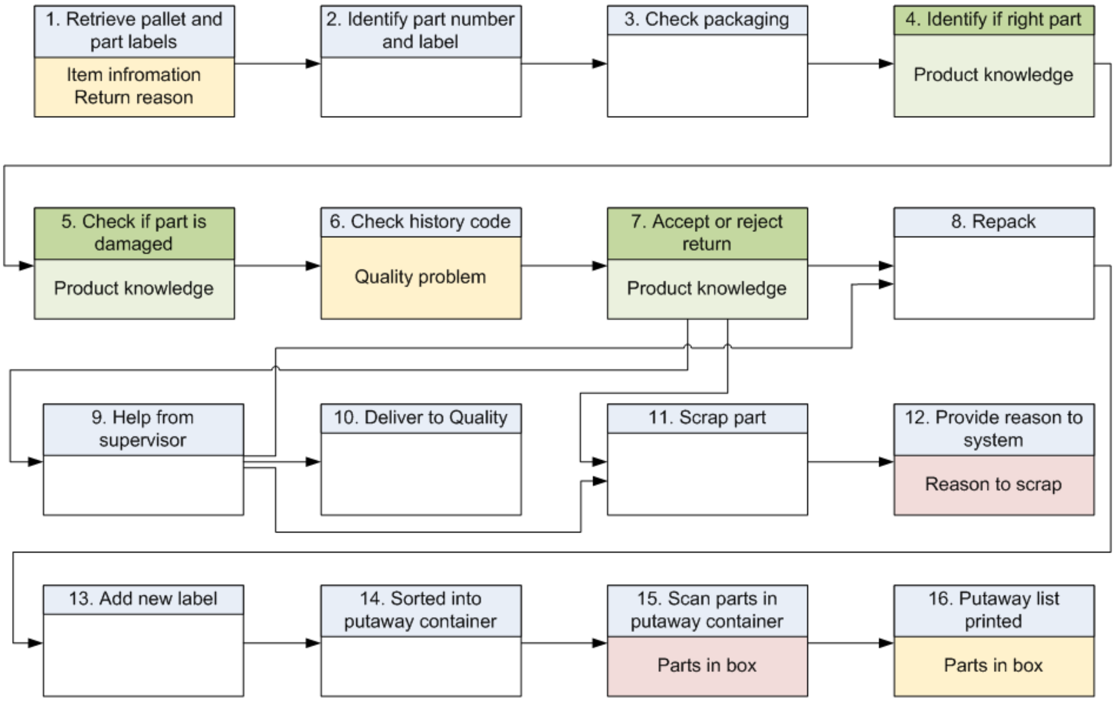

Figure 4.15: Return

Sorting & Packing for Dangerous Goods. The CDC in Gent handles a specific category of product: dangerous goods, these hazardous goods are only handled by CDC within Volvo. These goods are stored in a designated area separated from the rest of the goods and are handled by experienced and specially educated employees. The picking, sorting and packing are performed by the same employee in a sequential manner. The picking process does not differ from the picking of other parts and are therefore not included. However the packing process include some additional steps compared to the sorting and packing process in Eskilstuna and are thereof displayed in a process chart (Figure 4.16).

The operator need to sort the parts and match each order with the respective shipping label (1) and identify the SKUs for each order (2). On a screen the operator then upload the order number, destination and the part number (3), the system will give an alert if the parts in the order are not allowed to be packed in the same box. The operator will receive instructions whether the shipping container needs to be a cardboard box approved by UN standards or if a standard one can be used (4). The operator decides based on the box instructions which type and size of box to use (5) and confirm that and by scanning the corresponding shipping label (6). The parts are put in the box, filling material is added to ensure nothing moves inside the box during transport and the box is closed (7; 8). On the screen the operator will then receive instructions about special markings needed (9) and these ones are added to the box (10). If the transport time to customer is long the markings are secured with staples. The shipping slip is added on the box (11) and the operator confirms to the system that the packing is completed (12). At the same time as the completion of the order is reported the corresponding documents needed for the transport are received by the shipping department (13).

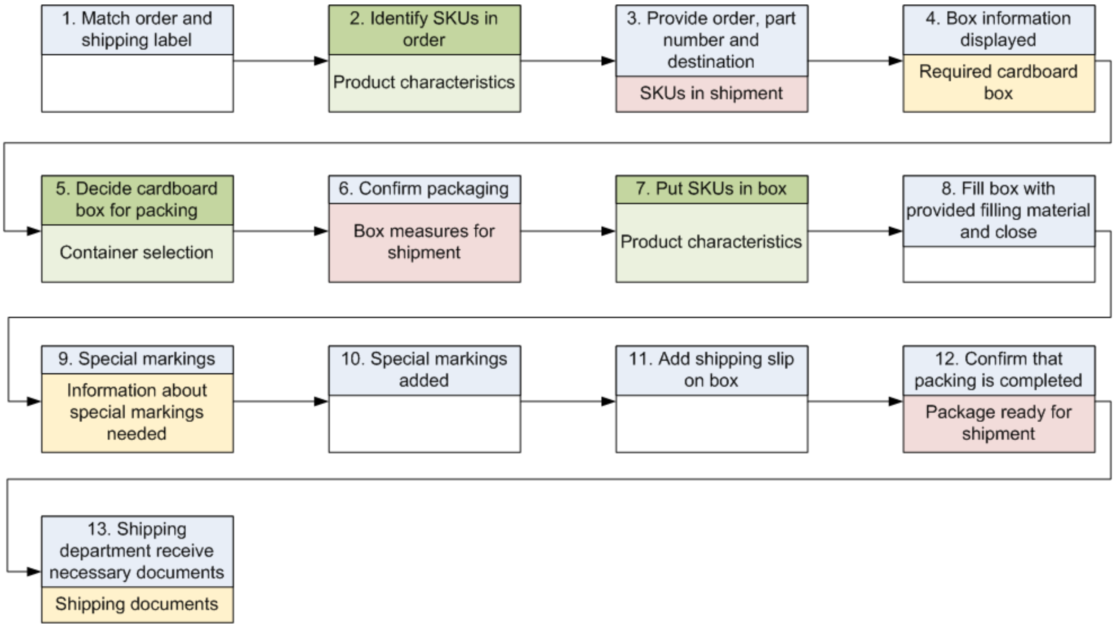

Figure 4.16: Sorting & Packing for Dangerous goods

Quality. Another function in the CDC is a physical quality check to ensure that all products delivered to and from the CDC are according to predetermined standards. The process of maintaining the quality in the CDC contains two processes. The first process is to check the quality of incoming goods and the second process is to verify a satisfying quality within the warehouse. In a smaller scale, the quality function also exists in Eskilstuna DC as well, although only the second process which is to control the goods in the warehouse. Since the process is more detailed in Gent the mapping has been performed there instead.

The first quality process, control the quality from external suppliers (Figure 4.17). The deliveries that are controlled are every supplier's first delivery to the CDC as well as samples from suppliers dependent on earlier quality problems. Four employees work with quality control of incoming goods. The operator gets instructions of what items to check and retrieve the corresponding pallet (1). Information about how many pieces in the delivery that should be controlled is provided (2). The parts are controlled towards primarily drawings and if that is not available pictures in the customer catalogue or lastly the part description (3). Based on the operator's knowledge about different parts characteristics a decision is made whether the quality of the parts are approved or not (4). If the part is approved and a first time delivery measures will be registered with a 3D-scanner, if necessary assigned an appropriate packaging and storage location for the part (5; 6; 7). Thereafter the putaway list is printed (8) for the part and they are delivered for sorting and putaway. If the part is not a first time delivery the putaway list is printed directly after the decision (4; 8). If the parts are rejected they are placed on a shelf to await supervisor attention (9). The supervisor then inspect the part (10) and if the supervisor approve the part it is sent back to the handler (4), but if the part is rejected also by the supervisor an inspection report is sent to the supplier (11). The supplier is then required to send back a response and an agreement how to handle and avoid the same mistakes in the future.

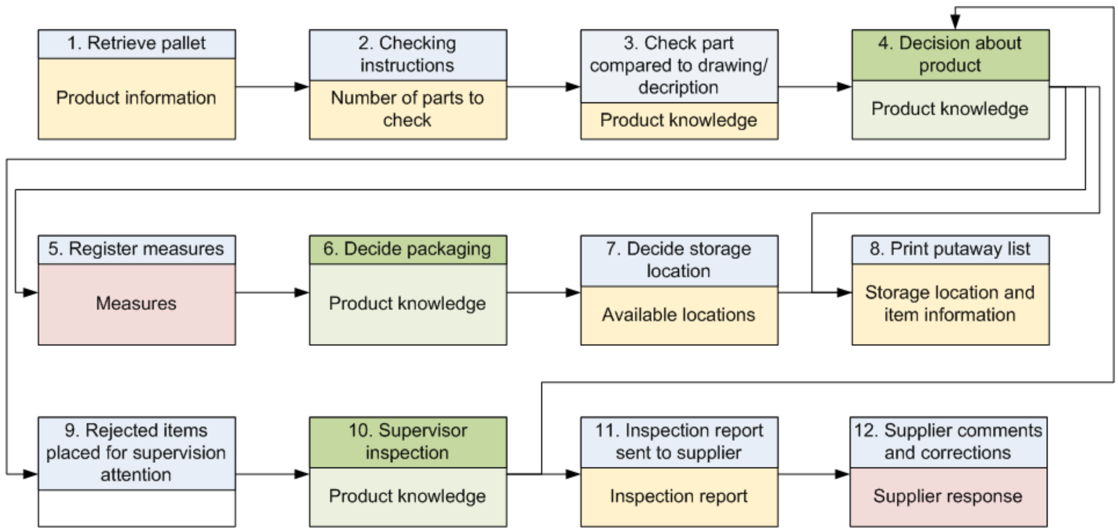

Figure 4.17: Quality check of goods arriving from suppliers

The second quality process, control the quality of the parts in the warehouse (Figure 4.18). The controls are made based on complaints from customers, on alerts from other operators about faulty quality or unknown parts, and products that the return process not is able to assess. The detailed knowledge the employees in this process need to possess to identify unknown parts requires extensive experience and an interest to understand the parts in the finalized products. To evaluate a part the operator need to identify the part (2), this might for unknown parts be the main task. This is for unknown parts done with product knowledge and a comprehensive understanding of the parts. For parts with a bar code the identification is done by comparing the part with drawings and descriptions that hopefully match. When the part is identified it is time for the quality control, the parts are compared with drawings and descriptions (3). Thereafter a decision regarding the product is made (4) and it is either scraped (5) or accepted and then if needed repacked and provided with a new label (6; 7). Finally the putaway list is printed (8) and the parts are delivered to sorting and putaway.

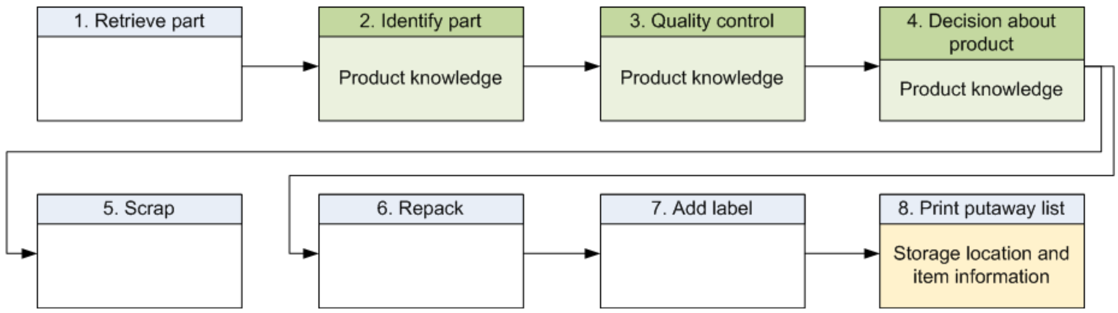

Figure 4.18: Quality check of goods from inventory

4.2.2 Experience Based Information in the Processes

The experience based information used within each of the processes was developed from literature (Section 2.1.1) and observation in the DC (Section 4.2.1). This information was compiled and presented for representatives from Gent CDC. Through correspondence by email the existing experience based information within the processes was confirmed and verified. The input for sorting and packing for dangerous goods was perceived to be the same as for sorting and packing in Eskilstuna DC (Figure 4.20), since all information connected the special characteristics of the goods are provided for the operators or connected to the picking process rather than packing and sorting. However, for the return and quality process additional information used was identified by the CDC employees, which will be presented in this chapter.

For product knowledge in return and quality (Figure 4.19; Figure 4.21), the operators in the processes can ensure the quality further by having knowledge of the components that are to be included in the product. For example if a product should include fasteners to be complete, knowledge of that complementing part would ensure a higher quality.

Return

- Product knowledge
  - Product dimensions
  - Physical attributes
  - Product components
  - Quality issues

Figure 4.19: Experience based information in return

Sorting & Packing for Dangerous Goods

- Product characteristics
  - Sharp
  - Heavy
  - Fragile
  - Product multiple
  - Frail surface

- Packaging instructions
  - Placement in shipping container
  - Container selection
  - Product placement
  - Filling material

Figure 4.20: Experience based information in sorting and packing for dangerous goods

Quality

- Product knowledge
  - Product dimensions
  - Physical attributes
  - Product components

Figure 4.21: Experience based information in quality

4.2.3 The Voice System

For the flow in the CDC which uses voice technology, operators use forklifts to travel in an inventory zone in serpentine pick paths based on a given set of order lines just like in Eskilstuna DC. However, instead of using scanners a pick-by-voice hardware is used which consists of three parts, a mobile terminal, a headset and a mobile printer. The terminal is able to display and collect information through a touchscreen and keypad. The headset can record what the user says and vocally communicate information to users. Lastly, a printer is mounted on the forklift which is able to print tags. Worth noting is that a new pick-by-voice solution is being tried out where no display exists to force users to listen to the voice commands instead of using the display. However, some of the operators evaluating the new voice system express concerns with the removal of the screen. The concerns are mainly of ergonomic reasons, including trouble hearing given information due to noisy work environments.

The inventory zone connected to the examined flow consists of the roughly 3000 most frequent parts across Volvo Penta, Construction, Trucks and Buss, which can fit into a pallet. Parts are distributed in the zone based on their characteristic, meaning that heavy items will be placed close to the route starting point while fragile items are placed close to the end. There is also one section for small items which are stored in small boxes in flow racks to allow for higher pick density. Orders that correspond to more than a certain volume of products will be picked individually, which means that some orders are packed and shipped without being sorted.

The picking process starts with order receival where all incoming orders are collected. From this list, batches of order lines to be picked are automatically created based on their physical volume. These batches are stored digitally and arranged according to departure time. When a picker is ready to start working on a new batch, a command to retrieve the next picking batch is given by the operator and the terminal will print a so called starting label. The starting label barcode is scanned which loads batch information to the terminal and initiates the start of the picking round. The picker will at that point be given information regarding the location of the first item to be picked in form of the location serial number. After traveling to the location, a location confirmation is carried out where the picker says the last three digits of the product number. Information regarding the quantity to be picked will thereafter be presented. As the picker collects a SKU into a pallet, the operator can count off the pieces grabbed and thereby use the system to keep track of the total amount of pieces picked. When the whole quantity has been picked, a product label for that SKU is printed and placed on one of the items and the picker will confirm that the pick is complete which initiates display of next picking location.

Normally, the picking quantity is equal to the number of pieces to be picked. However, in some cases the product to be picked is handled in picking multiples, which means that the picking quantity corresponds to a different amount of pieces. An example is air filters that are handled in cases of eight pieces each. In those cases, that information will be given to alert the picker. If no stock can be found at the picking location, the picker will transmit that information to the terminal. When the last item of the batch has been picked, a so called end label is printed and the picker moves to the packing area. The end label is scanned in a terminal to upload the actual turn-out of the picking process.

4.2.4 Current Pilots to Improve Performance

In Volvo LS continuous search for more cost effective logistics solutions, pilot projects are carried out as a step in evaluating new solutions. For the result in this thesis two of these pilots has been of interest and are therefore presented in this section. The first is a pilot that tries to display additional information for operators during picking in Gent CDC. The second one is soon to start in another Volvo LS DC, namely the CDC for the brand Renault in Lyon. It is about removing the sorting between picking and packing of goods to increase efficiency. It is presented in this section due to the similarity of operations and the close collaboration between the CDCs.

Additional information for order pickers in Gent CDC. To evaluate if the performance and quality can increase within the picking process a trial to provide the operators with additional useful information is tried out in Gent CDC. The attempt of aiding the operators is performed in a trial area, where physical signs provide the useful information for the SKUs. This is possible since dedicated SKU slots are used. Once the required information has been identified and for what SKU it is needed, a sign is put up at the SKU location. The information that so far has been made available through visualization in the trial area is different types of product characteristics. These characteristics include if there is risk for cut injuries, if the product is picked in multiples through broken case picking, if it is fragile, if the product is among the top ten products picked in wrong quantity or the top ten products with most damage complaints.

Sorting solution for Renault. An interview was conducted with an IT manager at Volvo to receive further insights to a new IT solution: Pick & Go that are to be implemented in the DC in Lyon. The DC in Lyon functions as a CDC for Renault trucks and a support DC warehouse for other brands. The IT manager explained that one of the most time-consuming and non-value adding processes in DC's are sorting of picked goods before packing them. To avoid this step in the process the IT solution that enables Pick & Go will provide the operators with the cardboard box before the picking route starts, allowing the operators to place the product in the right container during picking. The solution will enable an efficient packing since the steps that remains in the process are to add filling material, close the box and add the shipping slip on it. The sorting of the products as well as the placement in the right container is already performed by the picker.

The system will provide the cardboard box that should be used as the last part on the picking list. The picker will then grab all of the boxes for the batch to be picked and place them on the forklift. The cardboard boxes and the picking list are to be connected to a barcode that the picks can be confirmed against to ensure the right parts are placed and shipped to the right customer. Volvo LS WMS supplier has been developing the add-on solution that performs the calculations about the optimal cardboard box.

A prerequisite for a working solution, expect the new software, is correct measures of all parts. As well as the measures for the cardboard boxes available on each individual DC. Thus, the system need to know the dimensions of each part to calculate the cardboard box needed. If these measures are wrong the cardboard box provided by the system will be inaccurate and part may not fit. To ensure that this is not the case the dimensions registered within Volvos system for Renault truck has been verified. However, since this has only been done for the Renault trucks parts, if the solution is to be implemented in any other DC a prerequisite is that the dimensions of the rest of Volvos parts are verified. The data about the size of the parts will be retrieved from the system GLOPS and if any fault measures are discovered the data needs to be overwritten in that system. This is done by scanning the part in a CubiScan to ensure correctness of the updated measures. A problem occurs if one part is packed differently for different markets since the system only can contain one value. This will however not affect the Renault parts but might be a later challenge if the solution is to be implemented for the other DCs.

4.3 The Workshop Pick-by-AR

The workshop was arranged in collaboration between the academia and the industry with representatives both from Chalmers Technological University and practitioners from a range of different companies. During the workshop the participants could try order picking in a laboratory picking environment with both Google Glass and Microsoft Hololens. Apart from that the participants reflected on the experience and discussed the usefulness and possibilities with smart glasses, as well as the drawbacks and challenges still to be solved. The coming review of the discussed thoughts are organized and presented in relation to the respective performance measure. However, at the same time as this is valuable insights from practitioners and researchers, it is no published information that has been reviewed.

Productivity is likely to increase since an operator can receive visual directives to the next position and see both from where to grab and where to put the item. If the operator only follow the supporting graphics and not need to process information and make decisions about where to move.

Quality could be improved when additional information about special handling can be displayed to support the operator. This could be information about how an item preferably should be placed in the storage or what box, filling and orientation the item have when being packed for shipping. Furthermore, the amount of information displayed can vary between items and more information can be displayed for specific items. For example, if an item is particularly heavy or fragile that information can be valuable to support the operator. If an item is an unusual pick or if the item has had quality mistakes before the operator can be made aware of this.

Flexibility might be affected with a smart glasses implementation but there is nothing that can be identified to be better or worse compared to the alternatives. However, smart glasses have a menu and can be programmed to allow the operator to make changes directly in the WMS. The operator could for example move the location of a product and directly register that in the system. Thus, flexibility could be achieved if operators or managers can do these types of changes without consulting programmers, as long as the system supports that. Moreover, compared to the picking system pick-by-light smart glasses have the advantage of allowing for changes in the layout, like moving a shelf. However, these changes could be as easily done with the compared voice and scanner systems. So, smart glasses are not preferable regarding flexibility compared to the investigated solutions. However it is still a dimension that should be considered to avoid being locked-in or dependent on a system provider. It is also worth noticing that the smart glasses solution could provide both possibilities but also responsibilities for the users depending on the configuration of the solution.

Ergonomics was the performance measure perceived as the concern with smart glasses. One of the major issues raised was concerning how screened off from reality a user becomes while using smart glasses, which might be a problem when driving a forklift or affect the possibility to interact with colleagues. It was discussed that this effect may be less severe with the use of Google Glass compared to Microsoft Hololens. For the Hololens the limited display, where the graphical support is displayed, resulted in the need for much head movements but also limited overview of the task to be performed. Moreover, the weight could be seen as a problem if the devices are to be carried throughout eight hours shifts. However, the solution for Hololens was perceived as less exhausting for the eye than the Google Glass solution. The need to refocus to see the graphics in the Glass was by some users perceived as difficult, but might be explained by lack of experience. An advantageous feature could be the ability to adapt the support to the individual user and provide more customized support based on experience level. This could facilitate the learning and perhaps support users that make more mistakes for example in the end of a long day.

5 ANALYSIS

The analysis presents the result of the thesis. The analysis is divided into three main parts, type of information, potentials of smart glasses and main potentials. In each of the three steps has information from both the theoretical framework as well as the empirical data been used (Figure 5.1). The output from an earlier step has been used as input for the next step in the analysis process. The first part identifies what available information type in the processes today that is most beneficial to communicate with smart glasses. Chapter 5.2 lists the potentials of using smart glasses in the current processes but also potentials if the processes are to be changed. The output from the second step is the main potentials which are identified by gradual exclusion of the other alternatives. Lastly, in chapter 5.3 the main potentials are further investigated with quantifications and illustrations. However, before the analysis according to Figure 5.1 can start, a preparatory analysis is needed to discuss important or general factors related to the literature and the empirical data.

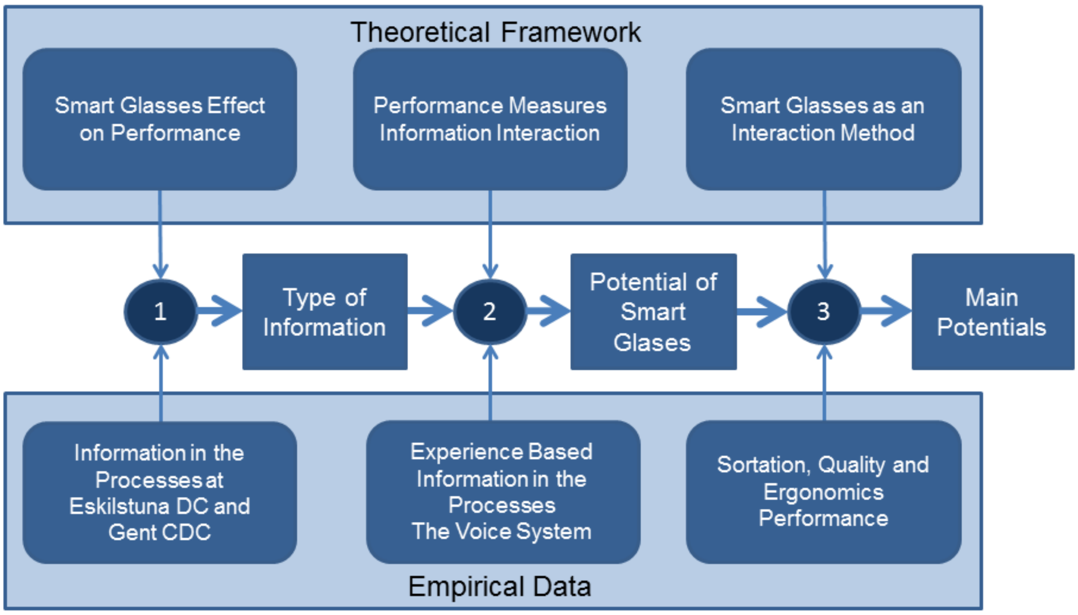

Figure 5.1: Structure of the analysis

To ensure the information used is relevant this section will start with a comparison between the context of previous smart glass studies and the Volvo LS DCs to analyze the applicability of previous research. Secondly, the research gap of smart glasses connected to the performance measure flexibility and lastly, the safety concerns connected to ergonomics raised both by previous researchers and the employees at Eskilstuna DC.

To make a proper analysis of smart glasses potential in a DC environment it is important to relate the learning's from literature to the context where it should be applied. All of the studies presented in the literature review as well as the workshop was performed in a laboratory environment and the setting investigated is an entire DC. Therefore it is of high importance to acknowledge the differences between the two different environments and how that may affect the performance measures. The most important differences identified are the picking density, the traveling distances, the operator's experience, the product characteristics and orderliness. As a spare parts warehouse, Eskilstuna DC has lower picking density, much longer traveling distances, more experienced workers, greater variety of products and is in a less orderly environment. This means that the times that can be improved by using smart glasses, meaning the time to interpret and understand tasks (Baumann et al., 2011; Schwerdtfeger et al., 2011) and the searching time (Glockner et al., 2014; Reif & Günthner, 2009) constitute a smaller portion of the total labor time spent in the DC compared to the laboratory environments. Thus, any productivity increase demonstrated within the laboratory environments can be expected to be smaller in the DC context, simply because a higher percentage of total time is spent on for example traveling, which is not improved. Therefore, the improved productivity is likely to be negligible in the DC context.

Furthermore, the high product variety entails an increased complexity of the processes in the DC, which creates a considerable need for special handling compared to the laboratory environment. Smart glasses can improve the quality by facilitate better handling of items (Reif & Walch, 2008); because of this the importance of smart glasses effect on quality in the DC context is emphasized. A higher variety further result in more experience based information within each of the processes. It is therefore highly unlikely that any of the operators can be up to date and know about all special cases that exist within the DC. Although the DC operators are familiar with the environment and a majority has much experience of working there. The long experience will however decrease the effort needed to understand and translate provided information. Moreover the products characteristics were in the studies of limited size, not fragile and relatively similar. In comparison the products in the DC are of high variety and the possibility to handle each of the products in a uniform way is an unreasonable assumption to make. Therefore the need for a flexible system that can handle different product types and changes of the system is a necessity. The last comparison to be made between the laboratory environment and a DC is the orderliness. It is unlikely that a DC will obtain the same level of orderliness as a laboratory environment, for example in terms of inventory accuracy, which might affect the actual turn-out of quality. In the DC it will usually be humans working that may make mistakes and to expect an environment with complete order is unreasonable. All of this is factors that need to be considered to enable a trustworthy result.

When studying the literature a research gap was identified. Based on the conceptual framework and the output from the workshop there has been no evidence for a connection between the use of smart glasses in a warehouse and flexibility. In the literature there was no connection to be found regarding flexibility, when the smart glasses are compared to a voice system and a scanner system (Chapter 2.4). However, from the workshop it was clear that smart glasses have an advantage concerning flexibility compared to a pick-by-light system (Chapter 4.3). But a light system is not a realistic alternative for a spare part DC and is therefore not a method that is included in the thesis. No existing link between flexibility and a smart glasses solution could be found, neither amongst the references in the theoretical framework nor through empirical findings. This does not mean that the link does not exist but it means that it is not included in the analysis. The authors are aware about this gap and see this as an opportunity for further research.

In regards to how ergonomics in general will be affected by implementing smart glasses for communication of information to DC operators, there are still many uncertainties, especially when it comes to long term usage. Previous research has stated that usage for extended periods of time has in some extent an effect on the human eye, but that it may be no different than using a regular desktop display (Klein-Theyer et al., 2016; Peli, 1998). Because forklifts are used in the DC operations, it is important to choose a smart glasses hardware and design with consideration to the field of view, as poor solutions will make it too narrow (Thomas & Sandor, 2009). This correlates with previous research stating a negative effect to driving ability with an increased amount of information displayed to an operator (Sun et al., 2015). However, it also entails that using smart glasses for display of information is safer than using other types displays because it can be displayed directly in the line of sight (Liu and Wen, 2004; Tippy et al., 2017). As stated by Due (2014), smart glasses may affect the social interaction of operators however, forklifts and voice systems already today impacts social interaction similarly and it is possible to remove these barriers during breaks.

5.1 Type of information

The first analysis step resulted in a decision about what information type to focus further on. This step limited the proceeding analysis and made it manageable. The input from literature was about smart glasses and how they perform in response to the performance measures. The empirical data used was the identified information types in Eskilstuna DC and Gent CDC. The identified information types are: received information that the worker currently get from either the internal or external system, transmitted information that the worker currently provide to the system and lastly information gained by working experience (Section 4.1.1; Section 4.2.1). Whether this information can be exchanged through smart glasses and how that could affect the performance measures was assessed for each of the information types.

Received information in Eskilstuna DC and Gent CDC are today delivered to the user with the use of papers, screens or scanner displays. Because the master data needed to display this information already exists, it is rather a question of how to display the same information but through smart glasses. The information that is provided to the workers in Eskilstuna DC and Gent CDC today are of similar sort as the information provided for the test subjects in the comparative studies which evaluated pick-by-vision, presented in the theoretical framework. The conclusion that can be made is that the productivity should increase if smart glasses are used compared to the current methods (Fager, 2016; Guo et al., 2015; Reif & Günthner, 2009; Reif & Walch, 2008; Schwerdtfeger et al., 2011; Weaver et al., 2010). However, the times affected by smart glasses are the time to interpret and understand information (Baumann et al., 2011; Schwerdtfeger et al., 2011) and the time to search for the right location (Glockner et al., 2014; Reif & Günthner, 2009). Taking the DC context into consideration, a relatively small part of total labor time is spent on the activities that can be improved, for example searching constitutes only 15% of the picking process in general (Bartholdi & Hackman, 2016). For a spare parts DC, this may be far less because generally the pick density is very low. Therefore it is believed that productivity improvements will not provide a significant difference. The quality is however likely to benefit from improved support (Baumann et al., 2011) and constant availability of necessary information (Glockner et al., 2014; Weaver et al., 2010). Because Eskilstuna DC already with current methods and processes are able to achieve very high quality, it is possible to question whether this benefit will be significant compared to using terminal or voice solutions. Lastly, displaying the received information with smart glasses is believed to be positive in an ergonomics perspective. The improvement would come from reduced cognitive load (Guo et al., 2015; Schwerdtfeger et al., 2011). In conclusion, there is some but limited potential to improve the performance measures with the use of smart glasses for the information received today. However, one of the main advantages of a smart glasses solution is the enhanced information that the user can interpret with the use of visualization (Spence, 2014). Thus, if only the information that already is received by the user is displayed, the full potential of a smart glasses solution is not utilized.

The transmitted information in Eskilstuna DC and Gent CDC are today sent to the WMS by the scanning of barcodes, with the keypad on the scanner or manual input to the system. As of today transmission of information with smart glasses would require a complementary solution (Fager 2016; Reif & Günthner, 2009). Because of this the performance of the transmitted information would currently be dependent on the confirmation method used together with a smart glasses implementation. Therefore, it would rather be the next step to investigate for a smart glasses solution, how the confirmation and transfer of information from the user and back to the WMS should be solved. Thus, a well thought out confirmation solution is essential for the performance of the smart glasses solution. However, this is not something that will be further assessed within the scope of this thesis (Figure 5.2). Lastly, worth mentioning is that when smart glasses continues to develop confirmation may be included and a complementary solution for confirmation may not be needed anymore.

The experienced based information in Eskilstuna DC is the knowledge that the workers have gained by experience and use in the daily operations. This is information that is not provided today and that is not evenly distributed amongst the workers. So, the level of this information and therefore the decisions made during the processes are dependent on the worker. This is one of the recognized advantages with information communication through smart glasses, the ability to share additional information with the user (Weaver et al., 2010). User can receive additional valuable information that function as decision support (Thomas & Sandor, 2009), for example information about deviations from standard procedure. This can improve the productivity due to both reduced times to assess special needs and more efficient decision making. The quality will be enhanced with improved information support regarding special handling as pertinent information facilitate that correct decisions are made. If once again the more general ergonomics concerns of using smart glasses are set aside, ergonomics performance could be improved by providing additional information which could facilitate a better task execution by the operator. However, it important to not add too much information since that will have an opposite effect on both productivity and quality (Baumann et al., 2011).

So, potential benefits with smart glasses can be found for the information types received and experience based information (Figure 5.2). However, the information type with highest potential was identified as the experience based information and therefore the most beneficial alternative to proceed with. However, this does not mean that any solution could consist of only such information. A final solution would have to include both the information that today is received and some of the information that today is experience based. So, the goal is to increase the level of received information the operators are provided. Thereof, is it important to evaluate what additional information that would be most beneficial to provide to the operators. Hence, the focus for the coming parts of the analysis will be on the experience based information and what additional information that can be beneficial to display.

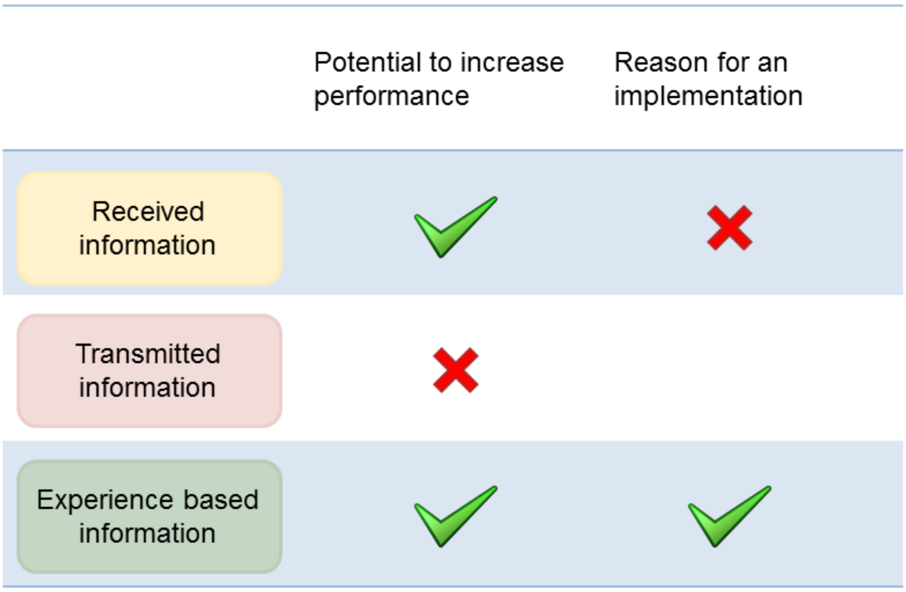

Figure 5.2: Result of the first analysis step

5.2 Potential of Smart Glasses

This subchapter constitutes the second step of the analysis structure (Figure 5.1). It is divided into three different subparts. The first analyzing potential of displaying additional experience based information to operators as the process looks like today. The second involves analysis of potential for solutions that require changes in current processes, solutions that are based on issues or suggestions raised by Volvo employees. Solutions that are considered to have potential in the first two parts are then in the third part further elaborated through initial assessment of solution impact versus complexity and if it is possible to achieve same solution with other technology than smart glasses. The outcome of this second step of the analysis is two solutions that are considered to have the highest potential which then will be used in the third analysis step.

5.2.1 Additional Information to Display in Existing Processes

The existing processes that contain experience based information are: sorting, putaway, picking, sorting and packing, loading, return, quality and dangerous goods (Section 4.1.1; Section 4.2.1). Based on the identified experience based information that could be displayed, the potential effect if that information is made available is identified. Thereafter a statement whether the effect could be a reason for an implementation is given. Potential effects that are considered interesting to further investigate is marked green while potential effects that are not interesting to look into is marked red.

Sorting. For the sorting process the information identified as experience based are the product’s characteristics (Section 4.1.2). Five different dimensions of product characteristics have been identified for the sorting process as being potentially advantageous for the operator to have when handling the products. Illustrating information regarding if the product is sharp, heavy or fragile could help the operators to handle products accordingly, assumed that they have been taught that earlier, which is positive in an ergonomics aspect. Alerting the operator about that the SKU is handled in multiples could reduce the cognitive load and reduce quantity mistakes. Furthermore, displaying when products are fragile or have frail surfaces could help increase operator awareness, thus increase quality. However, when items are sorted, the operator often need to pick up the product to find the SKU barcode and it is first then that the SKU and correlating information can be identified. If the product characteristics only can be displayed after handling the product, it is questionable if it would provide much benefit, at least in the ergonomics aspect. Any solution to this problem, such as placing SKU labels on the topside of products packed in Gent CDC before shipping to Eskilstuna DC or controlling the sequence that products get sorted are not realistic. At least not until Volvo LS has control over the content in the each of pallets delivered. Therefore it is also considered unrealistic or too costly to implement a solution where product characteristics can be displayed in sorting process and that it should not be investigated further (Figure 5.3).

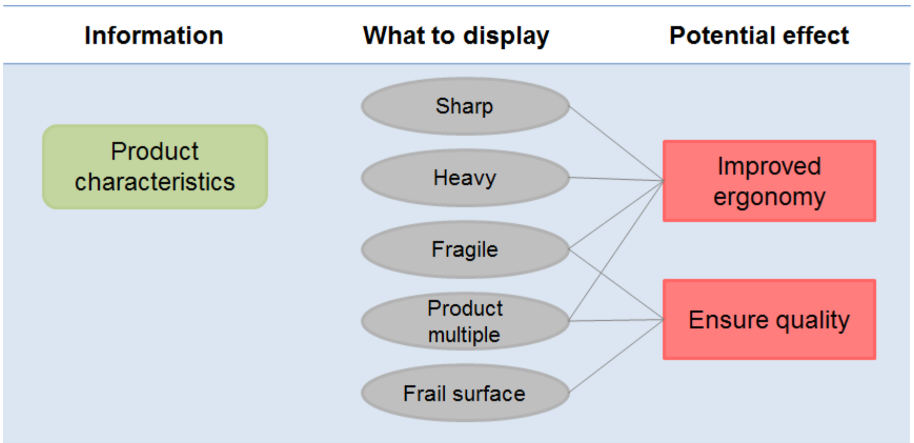

Figure 5.3:Analysis of experience based information in sortation

Putaway and Picking. Both product characteristics and transport information are relevant for both the putaway and picking process (Section 4.1.2). Because the processes are very similar and the same information has been identified as relevant for both processes, they are handled jointly in this chapter (Figure 4.10; Figure 4.11). Out of these two experienced based information types, only product characteristics is deemed to be worth investigating further. Because operators will handle the SKUs in a predefined sequence, it is possible to know what SKU that will be handled before actually handling it. The product characteristics are therefore possible to display before or in conjunction with the handling of a SKU, which can help increase the quality and ergonomics of the process (Figure 5.4).

When an operator is working within the DC, the operator's knowledge about the surroundings is quite limited by for example inventory shelves (Bartholdi & Hackman, 2016). By providing information regarding the distance to travel, layout or positions of other operators could help the operator to gain a better overview. A better awareness of the surroundings could help operators, especially those with little experience, to make better decisions for example regarding what paths to take. Furthermore, displaying information about speed or notifications about dangerous crossings where people usually walk or where other forklifts are crossing could provide an increased safety for operators. However, to display transport information, an extensive amount of data would need to be collected and processed, for example regarding detailed DC layout and live data from operators. This might be relevant at later stages but as of today that will have high or perhaps even unrealistic prerequisites for implementation, as there currently is no WMS available on the market that holds such detailed warehouse information (Bartholdi & Hackman, 2016). Furthermore it is possible to argue that information will not provide much benefit for operators that have much experience and may then be superfluous information that reduces cognitive ergonomics.

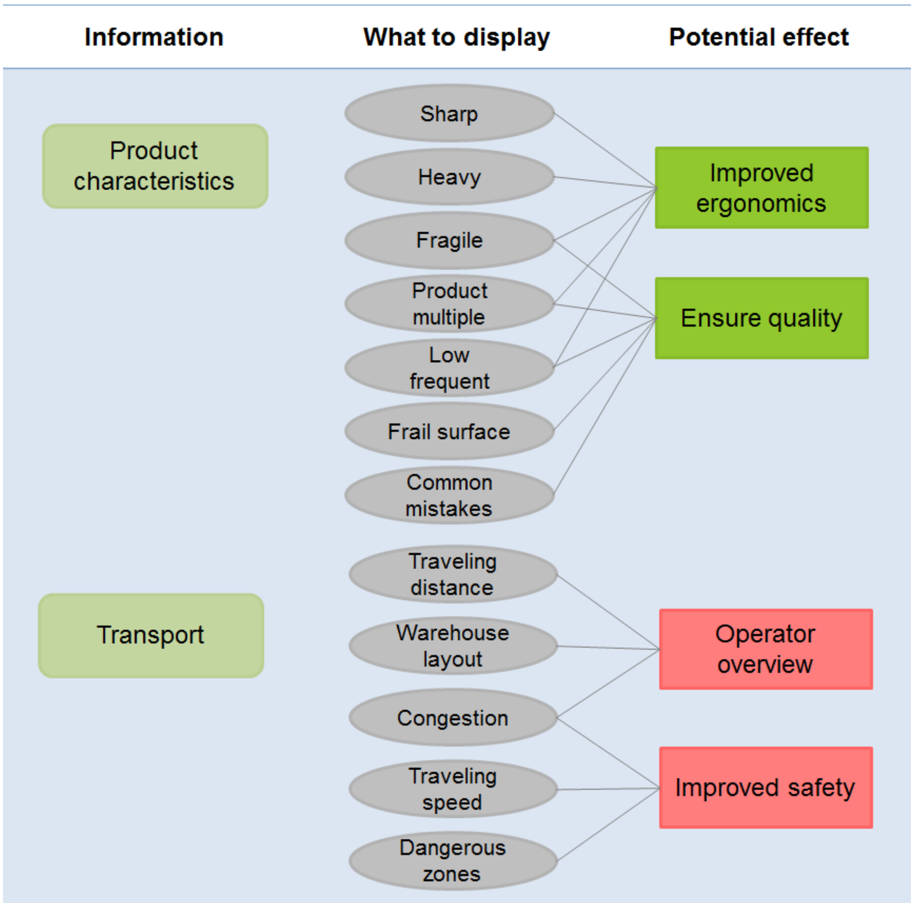

Figure 5.4: Analysis of experience based information in putaway and picking

Sorting & Packing. Within the process of sorting and packing, two different types of information, product characteristics and packing instructions, have been identified as potentially beneficial (Section 4.1.2). For product characteristics, following the same logic as for the sorting process, the potential is considered to not be worth investigating because of the difficulty of recognizing the SKU before the actual handling of the product (Figure 5.5). Packing instructions however, is believed to have a high potential. The possibility to provide operators information regarding what container to choose and how to pack items within the container for a specific order could help improve the packing process productivity. The reason would be that the time needed by the operator to make the decisions could be removed, as well as the time needed to repack products into a new larger container if wrong decision is taken and they do not fit in the container. The same information would also help increase the space utilization while packing since a hypothesis can be made that operators choose larger containers than what is needed to ensure that they do not need to repack the order. Further information as what filling material to choose and how to stack the containers on top of pallets or in shipping containers could further increase space efficiency and productivity. The prerequisites for displaying packing information could however be substantial. Information regarding the dimensions of all products and containers would be required and also a program that quickly can process packing algorithms for these.

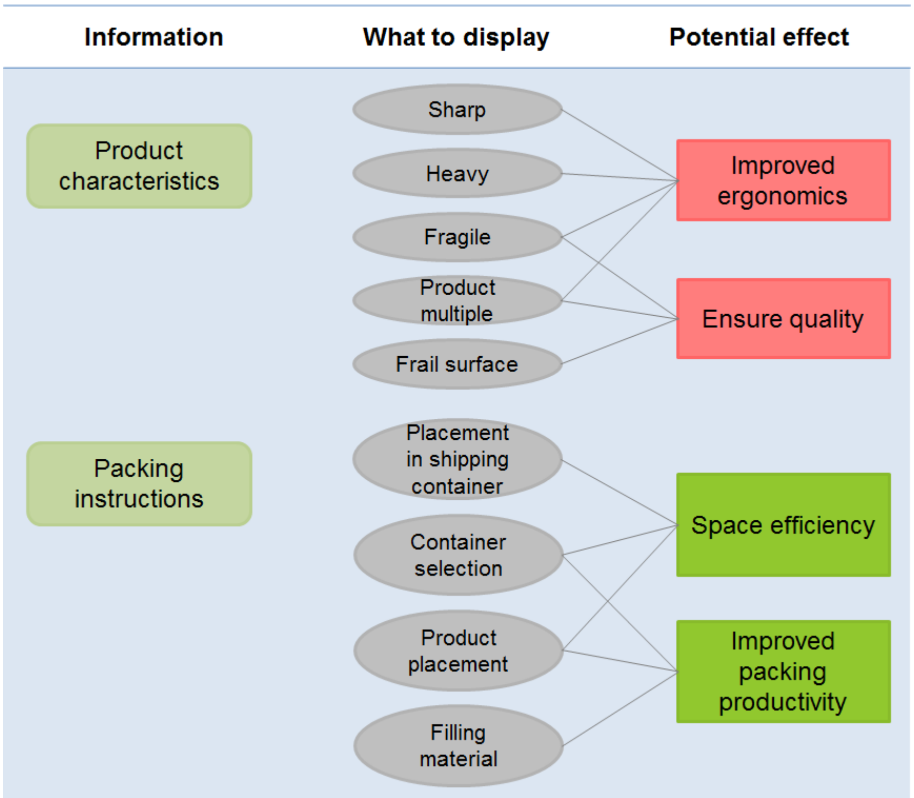

Figure 5.5: Analysis of experience based information in sorting and packing

Loading. After all orders have been packed, they need to be loaded onto trucks or containers leaving for outbound deliveries. While loading shipping containers or pallets, operators could benefit from receiving information on how to load the goods (Section 4.1.2). That information could not only increase truck fill rate and prevent damages during transportation, minimize total handling cost by loading with respect to the withdrawal to be conducted later on. To provide the information about how to load the goods would however require information of both how orders have been packed and staged as well as information about the truck and how it is loaded. Because third party logistics are used, several organizations could be sharing one truck, making it quite difficult to collect and manage that information for use in such an application. Therefore, loading instructions will not be further investigated in the thesis (Figure 5.6).

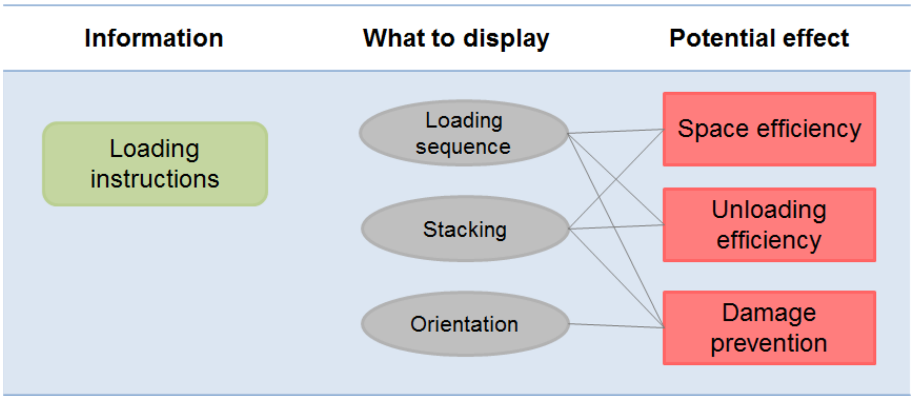

Figure 5.6: Analysis of experience based information in loading

Return. The return process and its efficiency rely heavily on the product knowledge experience of operators (Section 4.2.2). Memories of what the physical attributes, components and dimensions of products help operators to identify if it is indeed the correct product that has been returned, in the right quality. It is essential that the operator is able to make the right decision because products may be unnecessarily scrapped if the operator is unsure or incorrectly accepted and put into inventory, causing quality complaints later on. This type of information is already available today to a large extent in the company systems RAPID and GLOPS. The information is however not often used, quite possibly due to the inefficiency of retrieving it, making it more cost effective to take the risk of misjudgment compared to retrieve the information each time. Smart glasses is however a more efficient option for displaying said information which would motivate higher use of product information and less need for operator experience which is worth investigating further (Figure 5.7).

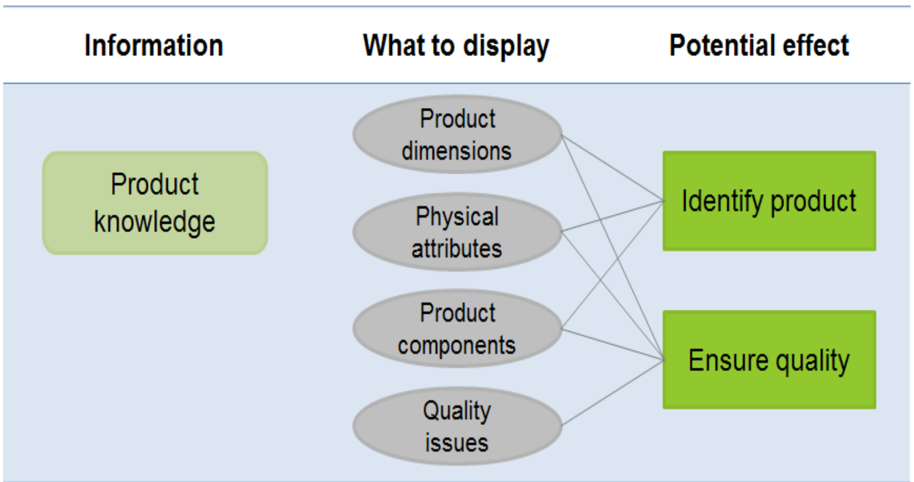

Figure 5.7: Analysis of experience based information in return

Quality. Within the quality process operators identify and control the quality of products, both within the warehouse and from suppliers (Section 4.2.2). The first part of the processes consists of supplier quality checks is a relatively well defined processes where the operator will ensure that the supplier maintain a satisfactory shipment quality. These checks are made based on statistical data and not for all data, meaning that only a percentage of all supplies are checked. A hypothesis is made that due to the lower volumes and higher importance of making the correct decision regarding the product quality, operators will use most or all information which they have access to via their desktop computer in a much higher degree than what is done in the returns process. The potential would then be that information can be accessed quicker and more productively. Although, the information that need to be accessed in this process may be more or equally efficiently accessed through the desktop computer as it is done today because of the information detail level that needs to be displayed in for example a drawing.

The second part of the quality process involves controlling inventory quality after customer complaints and identifying parts that are unknown, perhaps because the SKU label or shipment label has been lost. Quality control of parts that have reported quality issues are important to control and will similarly to supplier controls be conducted with high precision. For identifying and displaying information for items without any identification labels, the smart glasses would be required to have the ability to make 3D object identification. To the best of the authors' knowledge, such a solution is not supported today but might be possible in the future considering the Hololens capabilities of identifying the user's environment. In conclusion, the quality process, especially for the second part of it, is too arbitrary to have large benefits from a smart glasses implementation (Figure 5.8). Furthermore, even in a situation where most experience based information can be given to operators, it will most likely still be situations where operator expertise must be relied upon. Therefore, the quality process could with advantage be left as is to ensure that the operators remain as an expertise pool which can be consulted when needed.

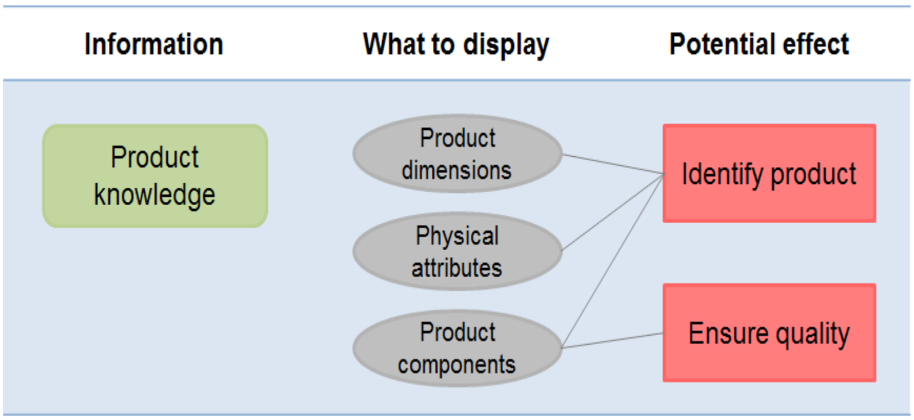

Figure 5.8: Analysis of experience based information in quality

Packing of Dangerous Goods. The process of packing dangerous goods could benefit by the addition of product characteristics and packing instruction information in the same way as the sorting and packing process (Section 4.2.2; Figure 5.9). Therefore a solution created could easily be adapted to both processes. Although, due to lower volumes, the potential savings are lower. However, the process of dangerous goods sorting and packing could be a good process to choose for evaluation a solution before further implementation.

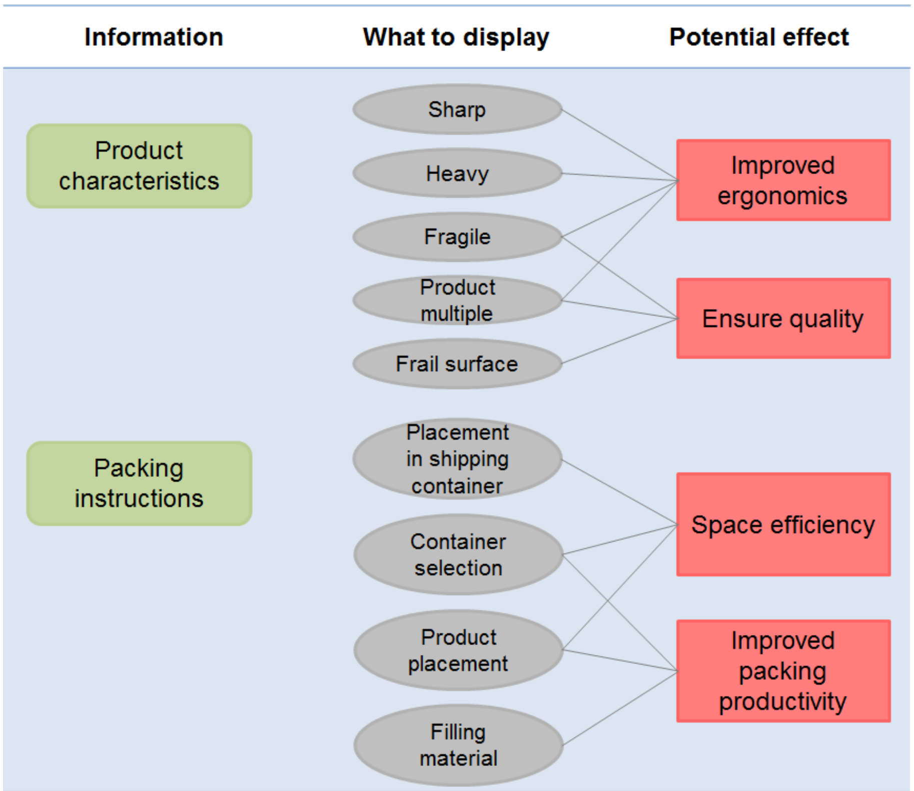

Figure 5.9: Analysis of experience based information in sorting and packing for dangerous goods

In conclusion, only three different types of information within four different processes have been identified to have a realistic potential in short term and therefore worth investigating further. However, over time when the technology matures, other potentials may arise. But as of today, the identified potentials for an implementation of smart glasses can be found for the putaway and picking process, sorting and packing, and returns. For putaway and picking, the potential is found in the ability to increase quality and ergonomics by displaying additional information for the operator. For sorting and packing is the potential found in the possibility to display the operator what shipping container to use in to limit the number of decisions in the process. That will entail improved productivity and better space efficiency. Lastly, for return the potential is to ease the identification of the parts and ensure the quality in the process by making available information more accessible.

5.2.2 Additional Information to Display with Process Changes

To assess the potential of smart glasses within the DC environment it was of value to discuss how the technology could be used to facilitate beneficial changes in the DC. During the visits at the two DC's, employees raised issues concerning the processes. Furthermore, where employees saw potential improvements that smart glasses could facilitate was also investigated. The identified issues that could be solved with smart glasses and the potential improvements are assessed and a statement regarding the potential is presented in following paragraphs.

Remove Labels in Sorting. Within the sorting process the general manager was displeased with inefficient searching after new labels that happened within the process

(Section 4.1.1). As it looks today the SKU labels for the content within one pallet is printed together at once. Then when the operators pick up the first part they need to locate the corresponding SKU label by searching through all of the printed labels until it is found. Moreover, there is one label printed for each SKU so if the same SKU are packed in multiple pallets the search for the correct amount of products becomes even more complex. This step in the process is time consuming and makes the process more complex and inefficient than what is needed. This problem is something that could be solved with the use of smart glasses that could read the part number of the SKU and then print the corresponding SKU label (Figure 5.10). This solution would increase the productivity and at the same time improve the worker satisfaction and ergonomics. Both ergonomics and worker satisfaction will improve when the tiring searching step is removed, which reduce the cognitive load in the process. However, if the printer is not fast enough it may be that the operator needs to stand and wait for the label to be printed. Then the productivity may be worse than it is today and the benefits of the implementation is reduced only to ergonomics.

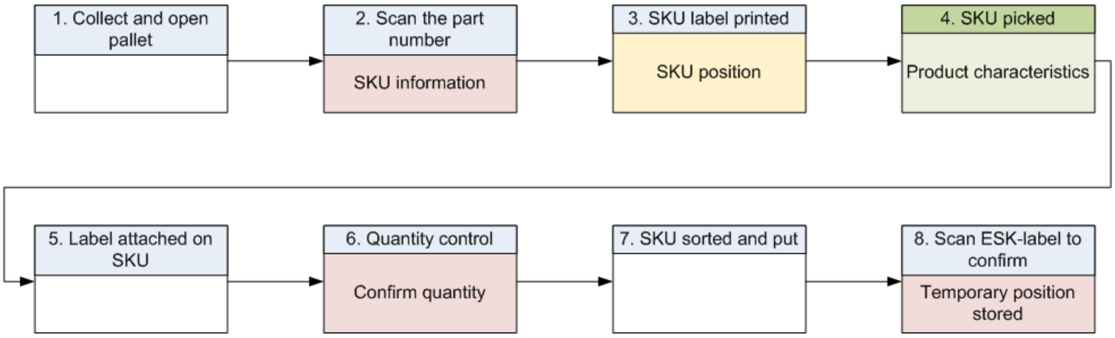

Figure 5.10: The sorting process with a smart glasses solution

Even if this is an imminent problem for the operators today and cause inefficiency, it is only a temporary problem. When Gent CDC change WMS and implement the same software as Eskilstuna DC use today the problem will disappear. The barcodes on the parts from Gent CDC will be scannable for the operators in Eskilstuna and the printing and adding of new labels will not be needed any longer (Figure 5.11). Because of this the potential of implementing a solution that remove the long list of labels and the searching for the labels are assumed to be negligible. The new process will contain fewer steps and be more efficient compared to the smart glasses solution which leads to the conclusion that there is no need to create a smart glass solution to facilitate the task of adding SKU labels to products in the sorting process.

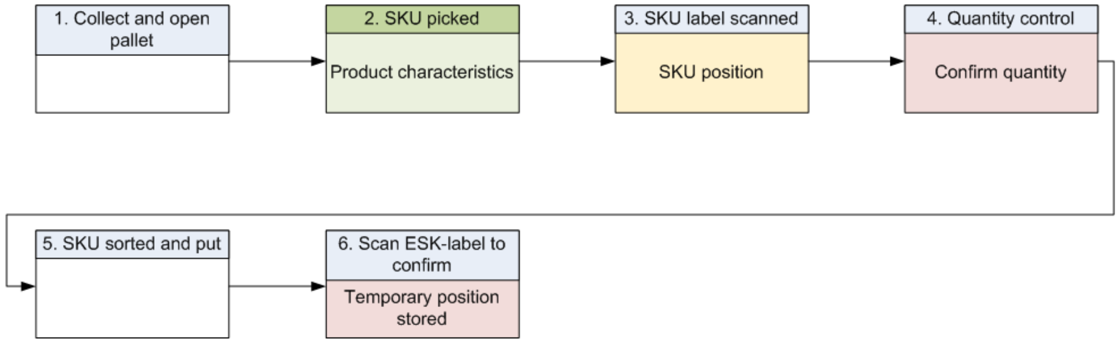

Figure 5.11: The new sorting process when the barcodes from Gent CDC are scannable

Remove Labels in Return. During the visit to Gent CDC and the observations of the return process (Section 4.2.1) the operator working in the process expressed hassle with the pile of SKU labels that was provided with every pallet. The operator in the process today needs to retrieve a pile of pre-printed labels for every SKU in a pallet of returned goods. Then when the first part is picked from the pallet to be identified, the corresponding label needs to be found. However, this would not be necessary if the labels could be printed when the part is identified or even better when the decision whether the part will be accepted or not is made. It would result in a more productive process since the operators not have to search for the right labels. Moreover if the labels are printed first after the decision regarding the product is made, labels for parts that are not to be accepted would not have to be printed at all. This would save both time and unnecessary handling of labels. In a second and more preferable scenario, the operator would have access to the same information as today on the labels but through a display instead.

The process would look more or less the same since the difference is connected to the handling of the labels and would not affect any other process steps (Figure 5.12). The difference are: the operator will retrieve only the pallets of goods and not the labels (1), when the part is scanned the operator receives the information visually and not from the label (2), when a product has been accepted, the new label is printed while the product is repacked and then added (8; 13). In this way, the SKU label could be printed in parallel with the step of repacking the product thus eliminating any potential waiting time for the label to be printed. Except improving productivity, operators are likely to experience better ergonomics due to less hassle and stress caused by the pile of labels they need to search for. If this solution then can be combined with the former solution, to make the information in the systems today more available in the return process, the improvements can be more extensive. If so, the workers could benefit both from reduced searching and handling of labels as well as improved decision support. Then perhaps it would be easier to introduce inexperienced personnel, facilitating replacement of for example workers on sick leave.

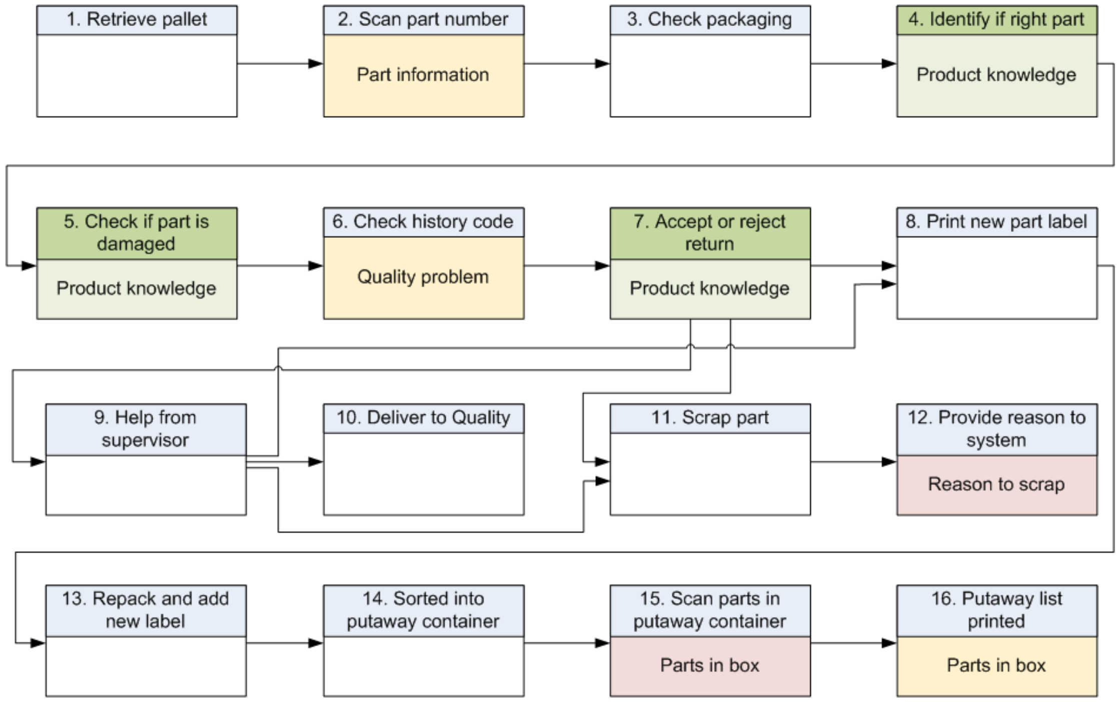

Figure 5.12: The new return process

Remove Sorting. During the visit to Eskilstuna DC (Chapter 4.1) one of the production managers raised awareness about the inefficiency of first picking the parts in a batch to later sort them before packing. The production manager had the idea that a worker perhaps could sort the parts when they are picked to avoid sorting and handling each item again. This could be realized if the picker got instructions about the sizes of the cardboard boxes before the picking route started. If the correct shipping container could be provided, the picker could both pick and put the products in the final box simultaneously. This assumes however that the picker can fit of all of the cardboard boxes on the forklift and is something that needs to be further evaluated. If the boxes fit, the solution would increase productivity and improve the quality of the shipment. Better productivity would be achieved since the second sorting would no longer be needed and better quality since the handling of the parts would be reduced which in extent also reduces the risk of making handling mistakes.

A solution enabling an integration of sorting in the picking process would reduce the steps at the packing station. At the same time would the picking process include more steps than before. In total would the number of steps be heavily reduced and the combined two processes would consist of twenty steps (Figure 5.13). Some extra steps has been added in the beginning when the operator receives information about the cardboard boxes used as shipping containers and place them in a pre-given order for picking (3; 4; 5). At the same time all steps connected to the identification and sorting of the packages that was performed in sorting and packing (Section 4.1.1), are no longer needed. Whether the process is to be performed by one operator or be split so that the forklifts can be fully utilized should be adapted to the warehouse resources.

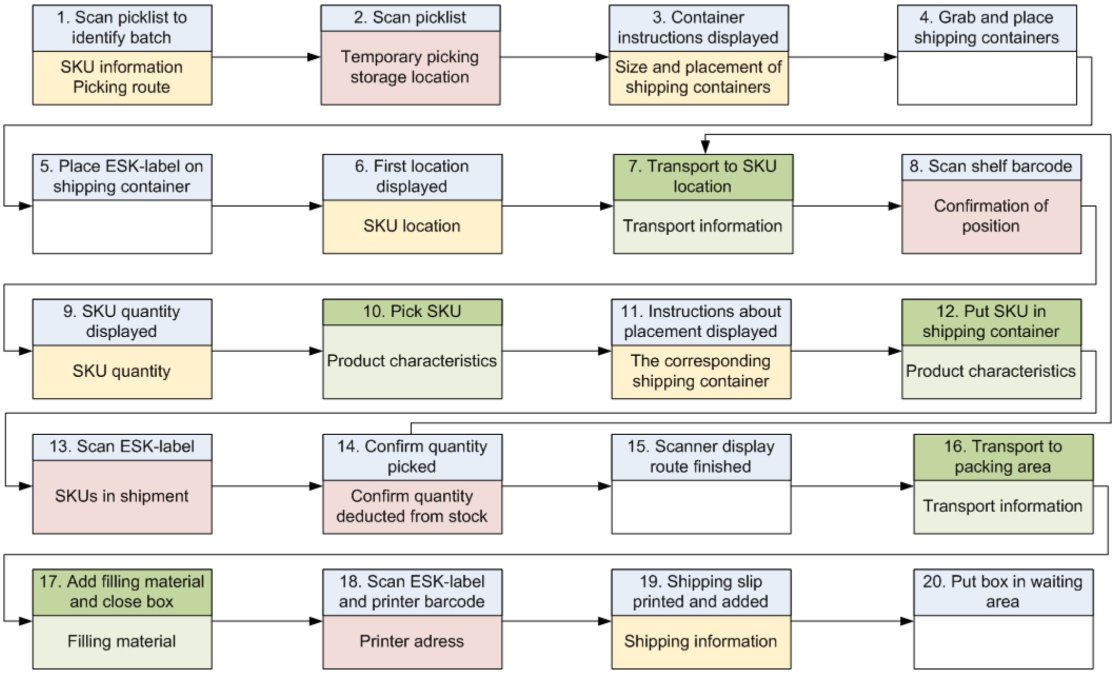

Figure 5.13: New picking and packing process

Avoid Shipping Air. The director for the division process and IT raised the question whether this technology could be used to avoid shipping air within the company (Section 4.1.1). This idea aims to reduce packaging material consumption and increase transport fill rate which also in turn means less transportation costs and environmental impact. There are several aspects that need to be fulfilled to achieve to not ship more air than needed. By applying the two earlier mentioned ideas about packing and loading instructions (Section 5.2.1), the aim to avoid shipping air can be partly achieved. However, when this is in place, there is still much to be done to make a difference. The boxes and cages in which the smaller packages are shipped in need to be changed if the pieces loaded on the trailers are to change. Moreover, perhaps the size of the preordered truck needs to be changed. Lastly, there is large potential to lower the air shipped by consolidating more in the warehouse. As of today SKUs from different zones in the warehouse are not consolidated but will always be shipped separately (Chapter 4.1). Another problem is that the orders arrive throughout the day and one customer might send for parts more than once during a day. If the first order from a customer has been batched for picking and a new one arrives they will be sent in different packages. Perhaps it would be possible to save the customers that are known to send many orders and pick those close to the cut of time or to save the picked parts from given customers and pack more infrequent than the picking is performed. However, consolidating products from different zones would add new process steps, thus decreasing productivity. If the system could optimize the packaging of products and shipping containers as well as consolidating products destined to the same customer from different zones in the DC, it would result in smaller shipment volumes and less consumption of packing material. When that is achieved it would be time to start analyzing whether the loading containers needs to be altered and if some of the ordered trucks can be smaller.

Out of these aspects that could lower the amount of shipped air, consolidation is seen as having greatest potential. This is because more parts in one package is more likely to have a greater effect on the fill rate compared to choosing the most suited box for packing. However, such solutions does not need or benefit from using smart glasses compared to the today used terminal solution, but is rather dependent on the practical issue of having a time efficient process for the consolidation itself. Because of this, the solution to avoid shipping air is not considered having a great potential, since it would not benefit from an implementation of smart glasses. Using smart glasses to avoid shipping air would therefore not be further investigated. However, the benefit of smaller packages is still included for the suggested solution to provide packing instructions in the sorting and packing process.

In conclusion, the Identified potentials if the processes are changed are found in the return process were the SKU labels could be removed to increase productivity in the process. Further potential to increase both productivity and quality can be found if sorting is removed and integrated in the picking process.

5.2.3 Suggestions with Potential

Derived from the suggestions from the two preceding subchapters, the five solutions that is considered to have an underlying potential will be further evaluated in this chapter. The five solutions are: displaying product characteristics in putaway and picking, providing packing instructions in sorting and packing, displaying available information in return, removing the labels in return and including the sortation in picking. After the discussion in this chapter the now five suggested solutions should culminate in the solutions to be further investigated and quantified. The decision is based on a discussion about the impact the solution would have on the business and the complexity of realizing the solution. Furthermore, a solution with smart glasses will be compared to that of using a voice system or a display to communicate the information.

With the help of Volvo employees, including one IT manager the impact the suggested solutions would have on the business and the complexity of developing and implement the solutions were estimated (Figure 5.14). The impact on the business was mostly connected to the volumes and number of parts affected by the solution. The complexity was connected to the demands on the current systems and need for new ones as well as the existing knowledge at Volvo LS. In Figure 5.14 shorter descriptions has been used for the solutions: Product Characteristics corresponds to displaying product characteristics in putaway and picking, Packing Instructions to providing packing instructions in sorting and packing, Product Information to displaying available information in return, Scan & Receive to removing the labels in return and Pick & Sort to including the sortation in picking.

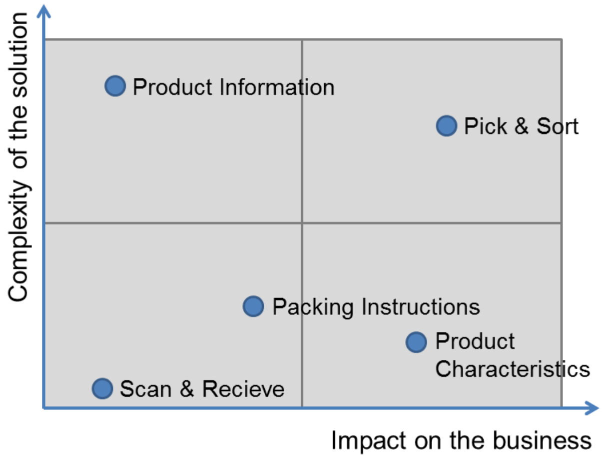

Figure 5.14: Matrix displaying the solutions complexity and impact on the business

Display Products Characteristic in PutAway and Picking. Providing the operator with information regarding product characteristics can help increase both ergonomics and operation quality in the putaway and picking process (Section 5.2.1). It would allow for increased awareness of the operator for specific SKUs that has been identified as problematic. This information is most important to highlight for SKUs that have low turnover or are otherwise particularly susceptible to mistakes since operator are least likely to have that knowledge by experience (Chapter 4.3; Section 4.1.2). By using smart glasses, the operator could be made aware of the product characteristics through adding that information in form of a symbol or text in the field of view. A terminal with a display could illustrate the same information (Figure 5.15). However, if the information were presented in a terminal, it will not be possible to receive it in parallel with other activities, such as grabbing of the product. Furthermore, if the information is not presented in conjunction with the activity, it will be easier for the operator to miss it, either because it is forgotten or not noticed at all. To present the information with a voice system would be possible, as is done in Gent CDC where the operator alert that the product is handled in picking multiples (Section 4.2.3). This occurs right before or in parallel with the operator grabbing the product. However, a large amount of information received through voice would decrease the cognitive ergonomics. It would therefore be of high importance to not provide the user with unnecessary information. Whether the implementation is done with a voice system or with smart glasses, it is important to not display information for the operators that not add additional value. It is however known that the level of information that could be interpreted is higher through sight than hearing (Stolovitch et al., 2011). Thus, more information can be provided through smart glasses compared to the voice system.

The research about usage of smart glasses in a warehouse environment is mainly focused on picking (Fager, 2016; Guo et al., 2015; Reif & Günthner, 2009; Reif & Walch, 2008; Weaver et al., 2010), indicating that this might be the area were the highest potential has been identified before. There are also available picking solutions using smart glasses on the market today (Evolar, 2014; Ubimax GmbH, 2017; Pcdata BV, 2016; Picavi GmbH, 2016), resulting in the complexity of developing a working solution is perceived as relatively low (Figure 5.14). The picking functionality is therefore an existing solution available on the market today and the part that is left to develop is the displaying of the additional information connected to specific SKUs. Furthermore, the impact a solution would have on the operations is perceived as high since the volumes that are picked every day is high. This is further emphasized by the fact that picking drives much of the total labor costs for a DC (Bartholdi & Hackman, 2016; Frazelle, 2016).

	Voice	Display	Smart Glasses
Product Characteristics	✓	✗	✓
Packing Instructions	✗	✓	✓
Product Information	✗	✓	✓
Scan & Receive	✗	✓	✓
Pick & Sort	✗	✗	✓

Figure 5.15: Illustration of whether the solutions could be realized with the different methods

Provide Packing Instructions in Sorting & Packing. Packing instructions could help increase packing productivity as well as the space utilization in shipments (Section 5.2.1). As an additional dimension comes the possibility to avoid shipping air (Section 5.2.2), which is an opportunity both for lower costs and reducing the environmental impact. The potential is dependent on how close to optimal operators are able to pack orders compared to a software solution. Furthermore, even though when the software is able to create instructions for an optimized packing of goods, it needs to be communicated to the operator. Due to the amount and complexity of information that needs to be communicated, for example the orientation of a product to be placed inside a box, it would be too inefficient to do so by a voice system (Figure 5.15). If using smart glasses, it would be possible to communicate the instructions by for example displaying holograms of how the product should be placed inside the box. Similarly, a display could visualize how products are to be packed. However, that would require the operator to look at the screen, which could be difficult to do in parallel with the packing of products as would be possible with smart glasses. Therefore will the placement of a screen be of high importance. However, if the information could be communicated through a display the operator would not have to wear the glasses. The impact on the business of this solution is dependent on how well the cardboard boxes are packed today. It is perceived that the boxes are packed relatively well since the operators have access to measuring tapes and use that when they are not sure what box that fits. So, the main savings potential is connected to productivity and is derived from the decision of what box to use. Even though there is potential connected to what cardboard box the operator should choose the potential for displaying how the corresponding box should be packed may be limited, resulting in a lower impact on the business even if the affected volumes are high (Figure 5.14). The complexity of the solution would be dependent on the level of interaction with reality and the graphics used but a simpler solution could be developed that are not to complex.

Display Available Information in Return. Enabling better access to the available product information in the returns process would increase the quality and ease the identification of products (Section 5.2.1). Ultimately leading to the requirements of experience for the employees working in the process could be reduced. Moreover, the number of faulty decisions made in the process is likely to decrease. The available information consists of both drawings and descriptions (Section 4.2.1). That type of information, especially the drawings, would only be possible to communicate through a display or with the use of smart glasses (Figure 5.15). This is since it would take too much time to deliver the information on a drawing with a voice system. It is however unclear if the cost of added time for understanding such information would be more costly for the organization, compared to the possible gains. Especially with consideration to the fact that the returns process handles small volumes compared to example the picking or packing process. Because of the smaller volumes is the impact the solution would have on the business perceived to be relatively low (Figure 5.14). The complexity of the system and how the information are to be displayed are high since the correct information need to be retrieved from the available systems and displayed in an appropriate way for the operator.

Remove Labels Return. Furthermore, limited volumes in the return process limit the impact for the scan & receive (Section 5.2.2) solution as well (Figure 5.14). However, the information printed on the SKU labels are less complex and more accessible making this suggestion less complex. Although the information displayed on the pre-printed SKU label is less complex and potentially could be communicated through voice system it is not preferable (Figure 5.15). Communicating the information with a voice system would increase the cognitive load of the operator as more information must be known and remembered. Furthermore, the information is still quite extensive and would not be time efficient if communicated with voice technology, since the operator can interpret more information simultaneously with sight compared to hearing (Stolovitch et al., 2011). The information could be communicated both with smart glasses and a display that are placed in the operator's field of vision during the process. Even if the impact of the solution is limited, this application may be a good project if the organization not find the other solutions beneficial enough but still would like to try the new technology to have the knowledge as the possibilities with smart glasses grow.

Include Sorting in Picking. Providing the operator with the shipping container before the picking process allows the operator to simultaneously pick and pack the product hence increasing the productivity (Section 5.2.2). When the sorting between the picking and packing process is no longer needed the material handling within the system decrease resulting in reduced risk for quality mistakes. Moreover, sorting of products that are picked and placed in the same container is a non-value adding activity that is time-consuming unnecessary. The picking is performed in batches with multiple customers, meaning that the solution would have to differentiate the boxes for the customers. If the cardboard boxes were to be placed in a numerical order and the operator confirmed the placement towards a corresponding barcode the solution could be possible with both a terminal and voice solution. The number of customers in each batch would however make it difficult for the operator to fit the boxes in a given order. If the boxes can fit, the solution would have to tell the operator how to place the boxes on the forklift and then provide visual support to tell the operator were to place the products to avoid mistakes. This is not something that could be presented on a display since the information would not be presented in conjunction with the activity, which is essential to ensure correct placement of the products. A voice system would not communicate the information sufficiently intuitive and easy to understand for the operators. Thus, smart glasses is the only alternative for the pick & sort solution (Figure 5.15).

There are available picking solutions with smart glasses on the market (DHL International, 2015) and Volvo LS have a pilot project that has developed an application that provide the optimal cardboard box for an order (Chapter 4.2.4), which could be used as a foundation for the development of the solution. This is nevertheless a complex solution that requires many applications and systems to work together. So, the complexity of pick & sort is high but also the impact the solution would have on the business (Figure 5.14). The order volume that the solution would affect is high and the potential savings regarding productivity is considerable.

In conclusion were one solution for the processes as the look today and one solution that would require a change of the processes selected to be further investigated. This was based on the volumes that went through the processes and the impact it would have on the business. However, the existing solutions on the market and the areas that has been mostly investigated provided an indication about others opinion of potential and was consequently taken into consideration. The solutions that are to be further investigated, illustrated and quantified are product characteristics and pick & sort.

5.3 Main Potentials

To further evaluate the potential of the two remaining smart glass solutions this chapter will present both of them more in detail. Both sections will start by once again presenting the solution together with a suggestion it could look like for the operator. Even though an illustration of how the solution might look for the operator is provided it is only one suggestion and not necessary the best one. This is followed by a discussion of identified prerequisites before an implementation besides the hardware and working software. Lastly, potential savings with both alternatives have been estimated. The chapter ends with a concluding discussion of the potential savings and how to proceed after the thesis.

5.3.1 Display Additional Information in Picking

The need of adding information regarding the characteristics of products seems to already have been identified in Gent CDC, as tests already are conducted by putting up physical signs for certain SKUs (Chapter 4.2.4). This solution is however quite inflexible. Firstly, it requires that the SKU slots are dedicated to certain positions so that the information displayed at a certain location is relevant for the specific SKU at the location. Secondly, there is a risk that a sign becomes irrelevant as underlying information may change. Lastly, the fact that the signs are physical drives a need for space for them at the SKU location and furthermore a need for maintaining the signs. Ultimately, these factors drive a need for labor, for example making sure that signs are moved together with SKUs or updating signs when there is need to do so. Although the rationale of putting up the signs is logical, the ability of storing that information and communicating it digitally would lead to significant scale benefits. Potentially, a central unit would be able to make changes for what information to display for which products in all DCs around the world in an instant. Furthermore, it would ensure that the information is up to date and that it belongs to the SKU that is to be handled. Building upon the concept of the physical signs, a smart glass solution could then provide the operators a view similar to what is suggested in the illustration in Figure 5.16. Here the top right corner of the operator's field of view is augmented with additional information while moving in the inventory space.

Figure 5.16: Illustration of operator view with two dimensional augmentations

The information identified to be of relevance is visualized through symbols to increase cognitive ergonomics (Figure 5.17). The symbols are a suggestion of intuitive symbols to use for communicating the identified product characteristics. Here a broken glass for fragile SKUs, a weight for heavy SKUs or a cut wound for sharp SKUs. Further, a box knife is used to signify that a product has a frail surface or can easily be scratched. The symbol with two boxes becoming one or one becoming two, illustrates that one unit to be picked consists of more than one piece or respectively involves opening cases to pick individual pieces. The red square is displayed to draw attention, perhaps illustrating that the product to be picked is a SKU with common mistakes or is a low frequently ordered SKU. The information regarding if the product is a low frequent part could alternatively be used to define which items that the information should be displayed for. For the most common items, operators are likely to already be aware of product characteristics and it may therefore be counterproductive to display it. In practice it may be required that the layout and amount of information is adjusted depending on the operator, especially if the experience level is much differentiated. As has been explained earlier, any additional information must act as a complement to what is already used today in the DC. Figure 5.16 displays an illustration of how the operator point of view could look like where both the quantity to be picked and SKU location is displayed. As presented, the information regarding SKU location could be augmented, perhaps facilitating the search of a specific location inside a shelf with many SKUs.

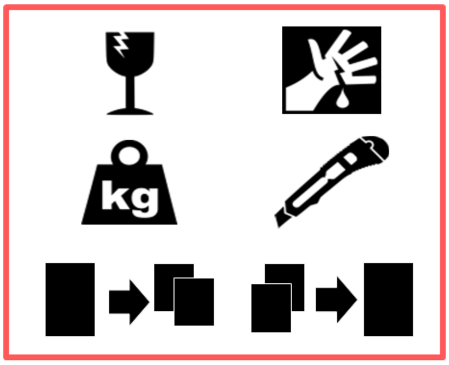

Figure 5.17: Illustration of product characteristics symbols

Another way to display the information is through a higher AR level, allowing for more interaction with the environment (Section 2.1.2). The interaction between information and environment allows further increased cognitive ergonomics, for example through highlighting the shelf position and displaying added information in direct connection to the SKU, illustrated in Figure 5.18. By doing so, operators can be guided intuitively to the correct position and the information is added only where it is needed. Despite that the solutions display the same information content both in the operator field of view, the more interactive solution would make the information more relatable to the activity and be less obstructive for the operator.

Figure 5.18: Illustration of operator view with two dimensional interactive augmentations

The perhaps most problematic precondition to display product characteristics for Volvo LS is that a database must be available, containing the information that shall be displayed for each SKU. Having all information stored digitally would limit the possibility of operators to make changes themselves compared to the previously mentioned signs, which is useful if for example there are inaccuracies or if new information needs to be developed. Therefore information streams would need to be set up so that information is collected from operators but also based on previous errors and initial information taking on new SKUs or updated SKUs. In addition to a systematically maintained database, creating a smart glass application for this purpose is a challenge. Today the scanners used in Eskilstuna access order data from the WMS, however product data is stored in a separate global database, GLOPS, and historical data regarding discrepancies or common mistakes are stored in a third system. Creating a solution which can access all three and communicate it to a pair of smart glasses used by an operator might therefore prove to be challenging. Although, the pilot in Lyon CDC where information from both GLOPS and DLX is used, proves that there is possibility to do that.

To make a monetary assessment on the potential of implementing a solution to display product characteristics in Eskilstuna DC, an estimation of the savings was made. This estimation is based on the 2016 costs in Eskilstuna DC related to discrepancies, scrapping and ergonomics (Section 4.1.3; 4.1.4). From scrapping records, a total value of 3000 SEK was scrapped. From ergonomics data, a total cost of 287 000 in 2016 is reported to have pain in shoulders, neck, back or other movement organs as main reason. Lastly, the cost of discrepancies, meaning quality complaints on orders sent from Eskilstuna DC, amounted to about 580 000 SEK (Table 5.1). This assumes that the average discrepancy cost produced for discrepancies in Gent CDC also can be used for Eskilstuna DC. Out of the four recorded types of discrepancies shown in table 5.1, three are considered to be improved by adding information regarding product characteristics. Under and over deliveries, could decrease by providing information regarding picking multiples thus increasing accuracy of number of pieces picked. Further, the number of damaged parts could be improved by making the operator aware when SKUs to be handled are fragile.

Table 5.1: Cost and share of total cost of each discrepancy category

Under Delivery	Over Delivery	Wrong Part	Damaged Part
345 000 SEK	16 000 SEK	139 000 SEK	79 000 SEK
59.6%	2.8%	24.0%	13.6%

Assuming that all sick absence reported due to pain in movement organs is a result from strain injuries caused at Eskilstuna, and that all scrapping and discrepancies could be avoided, A total of about 730 000 SEK could be saved at the most. However, not all damaged parts attributed to mistreatment in the Eskilstuna DC, since the product may break during transport or be broken inside its packaging already when arriving to Eskilstuna DC. Neither is all under or over deliveries attributed to the issue of picking multiples or all strain injuries caused by unawareness of product characteristics. Table 5.2 demonstrates how large the savings potential would be based on a few different scenarios of effect rate. In Oxenburgh, Marlow and Oxenburgh's (2004) assumptions and review of 250 cases of ergonomics interventions, it is stated that solutions that rely on employee behavior (such as training) are usually about 10 % effective. Assuming that a similar result could be expected in this case, the savings would be around 73 000 SEK. That does however not take all aspects into account. For example, the amount of over delivery discrepancies could reasonably be expected to be underrepresented since there is are no incentives for a customer to make complaints for receiving more than supposed. If the over deliveries are as many as the under deliveries, an additional 45 % saving could be expected meaning 106 000 SEK with a 10% impact rate. In addition, more accurately executed orders lead to higher inventory accuracy which may reduce the number of nilpicks and the cost of handling them (Section 4.1.3).

Table 5.2: Estimation of yearly savings

Impact Rate	5%	10%	20%	40%
Resulting Yearly Savings	36 500 SEK	73 000 SEK	146 000 SEK	292 000 SEK

5.3.2 Include Sorting in the Picking Process

Providing the operator with the shipping container before the picking process allows the operator to simultaneously pick and pack the product. The possibility to increase productivity by picking directly in the cardboard box that is to be shipped has been acknowledged in the CDC in Lyon (Chapter 4.2.4). The solution calculates the cardboard box needed to fit all of the parts for one customer order. Meaning, the operator can know before the picking start which boxes that is necessary to bring. However, one problem with the solution is how the operators are to know in which box to put the products. One way to handle this is to number the boxes and provide a reference to that number after an item has been picked. To ensure the quality the operator would scan a barcode on the box before placing the part in the box. This is a solution that could work well if the operators are to keep track of a limited number of cardboard boxes. However, when the number of customers in one batch is higher, like in Eskilstuna the solution would lose productivity since the operators need to search for the right number. Then a support system that guides the operator to the right box could be suitable. Based on the fact that the sight is the human's predominant sense for interpreting and understanding information (Stolovitch et al., 2011), it would be most effective to communicate the information visually. Smart glasses are visual tools that could facilitate an intuitive solution for placement. Both placement of the cardboard box on the pallets and picking mopeds as well as the placement of products in the correct box during picking could be communicated through augmentation.

Given the process chart for the new picking and packing process (Figure 5.13), all of the information marked as received information need to be displayed in the glasses. Notable is that the process chart has assumed that scanning of barcodes are still to be used as confirmation system. However, if smart glasses were to be combined with a voice system for confirmation the productivity would increase further. The discussion about a suitable confirmation system for the solution is however not further elaborated and the remaining part of the illustration will assume that a scanner is used since that is the current confirmation alternative in Eskilstuna DC.

First, the information about the batch need to be loaded to the smart glasses, whether this is completed by scanning the picking lists barcodes or automatically depends on the system configuration. Regardless of how, when the operator has been assigned a batch the smart glasses need to display which cardboard boxes that are to be placed where. How the boxes are to be placed can be displayed either with a two dimensional grid highlighting the type of box needed and where to put that specific box (Figure 5.19). This might be a sufficient solution for this step of the process since it provides information about the box and the placement. However, if the operator could see the type of box and the placement of that box on the pallet or the designated area the placement of the products are perceived to be faster and more intuitive (Figure 5.20).

Figure 5.19: Two dimensional illustration of how to place the box

Figure 5.20: Interactive two dimensional illustration of how to place the box

Thereafter, when all of the cardboard boxes are placed at the pallet or the area on the picking moped the picking of parts can start. During picking process the operator must be provided with the information that is currently communicated, such as SKU position and quantity, for example as suggested in section 5.3.1 (Figure 5.16). When the right SKU position has been found and confirmed, the picker should pick the parts and place them in the corresponding box. This is something that could be done with a two dimensional grid (Figure 5.21). The grid solution might work well as long as the number of boxes are limited, meaning the picker only picks for a limited number of customers. The orders that Eskilstuna DC need to fulfill usually contain few order lines each. Few order lines per order implies that the picker needs to pick many customers simultaneously to achieve a satisfying productivity. Therefore, a solution that more effectively could point the operator to the right cardboard box would enable picking of more customer orders in each batch (Figure 5.22). Both the correct box and the corresponding quantity to be put in the box needs to be displayed. Furthermore, the part number might be helpful to ensure the quality. The operator would have to confirm both the placement and the quantity to the system. When all products have been picked the operator will transport the boxes to a printer, close the boxes and add the shipping slip on the boxes before they are sorted according to destination.

Figure 5.21: Two dimensional illustration of where to place the part during picking

Figure 5.22: Interactive two dimensional illustration of how to place the part during picking

The level of augmentation needed for the solution will affect the hardware needed for the solution. Due to the characteristics of the orders in Eskilstuna DC, many orders with few order lines each, the solution that interacts with the surrounding environment is considered necessary to ensure both productivity and quality (Figure 5.20; Figure 5.22). With the two dimensional illustration (Figure 5.19; Figure 5.21), the risk of either placing the parts wrong or spending unnecessary time to interpret the grinds and understand what box is the right one is estimated to be high.

One of the preconditions for a solution enable the operator to simultaneously pick the parts and sort them into the cardboard boxes used for shipping, is that the boxes for one batch need to fit on the forklift used for that picking area. The solution need to be designed so that a batch only contains boxes that can fit on the forklift. Thereof, is it of interest to discover if it is feasible to fit the current batches on the respective forklift. The ability to fit all of the packed cardboard boxes from one batches on the forklift used was tried for both the areas with small and medium sized parts. The result indicates that the packages in the area for small parts fitted on the forklifts for all of the tried batches (Section 4.1.5). However, for the area with medium sized parts was it the opposite, the packages never fitted properly on the forklift. The result might not display the full truth since only a limited amount of batches were tested. However, it provides an indication about whether the boxes would fit or not. With this result it was concluded that the solution had highest potential for the area with small parts. Not excluding any potential for the area with medium size parts, but the remaining analysis will focus on the small parts. Moreover, in the area for small parts was a potential to fit more cardboard boxes on the forklifts identified. Indicating a possibility to increasing the sizes of the batches and therefore increase the productivity in picking.

Since parts of what is currently done in the sorting and packing process will instead be carried out in the picking process, it may increase total amount of time spent on specifically the picking process. Since forklifts are used in said process, the new solution will increase forklift occupation compared to current situation. This indicates that an investment to increase the number of forklifts in the DC might be needed. However, with the predicted productivity increase these two factors might even out each other, but this is still a factor that should be taken into consideration. Another alternative if the investment is needed would be to let one operator pick the batch and another to print the shipping slips, close the boxes and sort the packages according to destination.

One prerequisite the Lyon CDC stated for the solution was the quality of the dimensions data (Section 4.2.4). If the dimensions in the system are incorrect, the size of the calculated cardboard box will not be suitable for the parts and the parts may not fit. Because of this a certain percentage of the parts need to have the right measures registered to introduce the solution. To ensure that the right measures are registered all parts need to have a standard packaging which according to the employees at Eskilstuna DC is not the case today. However, it is likely to assume that a system like this would force the packaging for each part to become standardized the longer it is in operation. In any case this is an important prerequisite that needs to be considered before any application like this can be implemented in the DC.

It is not unreasonable to assume that the solution would result in significant savings for Volvo LS. Therefore have calculation to estimate the potential of the solution been made. The calculations use the yearly number of order lines in the zone for small parts, the cost for one employee during an hour and the time currently spent on sorting in the small zone per order line. Resulting in yearly saving of 214 000 SEK (Section 4.1.5). The calculations for the estimated savings potential only includes the savings in time that will come from the removed sorting step. Since, the time currently spent at sorting the products before packing them can be saved if the parts are placed directly in the correct box. However, more savings can be achieved with larger and optimal batches. These optimal batches can be created based on the size of the cardboard boxes and would result in improved productivity in the picking process. So, there are significant saving that can be done with this solution and the likelihood of the savings being even greater is high.

If the savings potential looks promising the question what the solution would cost to develop remains. The functionality in the WMS system is something that has been developed for another DC (Section 4.2.4), and should be possible to use also for Eskilstuna DC. Besides that comes the cost of developing the software for the smart glasses. This is an unexplored area and some further investigations are required to make a fair estimation. The hardware is another investment needed to use the visualization. Among the existing smart glasses investigated the Hololens is the one that could provide the needed functionality (Section 2.1.2).

In conclusion both examined potentials have a considerable cost savings potential and should be taken into account in considerations regarding an implementation of smart glasses. The preliminary estimations indicate that 73 000 SEK for displaying product characteristics and 214 000 SEK for the sortation solution could be saved yearly. Moreover, the discussion indicated that there might be additional saving not included in the quantification for both suggestions. The largest savings is estimated to be made through including sorting in the picking process. Due to the great potential and the belief that the technology development has only just begun, this is an alternative that deserves to be investigated further. The next step might be to look further into any additional savings potential and to estimate the corresponding cost to develop the solution. Thereafter if the business case is favorable for the solution a proof of concept should be done, suggestively in a smaller scale within the dangerous goods picking in Gent CDC.

6 DISCUSSION

The discussion is divided into four parts. Firstly, the methodology and result is discussed, followed by suggested topics for further research and the implications of the thesis. Then, areas of interest for smart glasses identified but not included in the scope of the thesis are discussed. Finally, the discussion ends with a discussion about the technology development and other emerging technologies that may impact the need for smart glasses.

6.1 Discussion of Result and Methodology

To find the potential of smart glasses, a method of exploring actual processes and thoughts or problems of people closest to the application area has been used. Most of the interactions with Volvo employees have been dependent on the company contacts available and not a conscious selection. This means that there could have been occasions where another employee would have been a more appropriate source. Furthermore, since all interactions are within one network of contacts, the findings may be biased. However, to carry out the project efficiently, it was seen as a necessity to use the existing connections.

Regarding the data collection, the data collected in form of interviews and observations has been verified to ensure that it has been correctly understood. Regarding the time study conducted, the sample size of 140 order lines may not be large enough to be statistically significant. However, it is used not as evidence but instead as an indication although it should be noted that any error in the average sorting time measured will impact the calculated savings potential.

In the thesis, the stated potentials were based on the processes as they are today (Section 5.2.1) and with the help of Volvo LS employees the potentials if the processes were to be changed (Section 5.2.2). Perhaps other potential solutions would have been identified if the current processes not had been used as a reference point. However, the reasoning might then have lacked a structure and some of the now identified potentials might have been overlooked. If the changes that could be made to the processes were influenced by someone outside the operations, additional ideas might have been acknowledged. However, it is fair to assume that the individuals that are most suited to evaluate the technology and the potentials with it in the operations are the employees working in the processes. The level of understanding of the possibilities with smart glasses amongst the employees can be questioned. Perhaps additional ideas could have been disclosed if the operators instead would have been gathered for a brainstorming workshop.

Whether the result is generalizable indicates to what extent the result from the specific case can be used for other cases (Maxwell, 2013). Due to the included process charts the result could be compared with other processes and if similar, the result might be applicable. The processes between warehouses have many similarities and the reasoning and statement for each of the processes (Section 5.2.1) could be useful as a reference point for other warehouses. It was concluded that the processes within Eskilstuna DC and Gent CDC was similar with the main difference being the volumes handled. However, only with caution should the result from a specific case be used for another case. The framework developed with literature could on the other hand be seen as general. As a contribution for future studies, the compilation of smart glasses effect on the DC performance measures could be considered.

6.2 Further Studies

Four areas worth investigating further have been identified. The first three are connected to the fact that it is an emerging technology that has been investigated, why further studies are required to asses both additional potentials as well as potential obstacles with the implementation. The fourth area discussed concern the continuation of this particular study.

The first area is the importance of continuously investigate potential applications of smart glasses since the technology continues to develop. When both the hardware and the software in the smart glasses become more sophisticated and robust, the possible applications will increase. Thus, it is essential to continue to investigate potential applications in parallel to the development.

Secondly, there was an identified gap in previous research. This gap was connected to the usage of smart glasses in a warehouse environment compared to the measures used to evaluate warehouse performance. No research that investigated whether smart glasses would affect the warehouse flexibility was found. This is a gap that should be explored to properly assess smart glasses potential in a warehouse environment.

Moreover, a concern that both managers and operators had concerning smart glasses was how the technology would affect the operator. It is therefore essential to determine whether usage could lead to ergonomic problems or not. The short term effect of usage has been investigated and it has been found that the usage is as harmful as working in front of a regular screen (Chapter 5.1). However, since the technology is new, any long term effects of usage has not yet been possible to assess, it is something that should be further investigated to ensure the operator's health. This is something that preferably should be done or at least estimated before a full scale implementation.

Lastly, to continue this thesis and develop the identified solutions further the next steps would be to: assess the costs of implementation, investigate a suitable solution for confirmation and provide a proof of concept. Now when an initial estimation of the potential savings connected to an implementation is done the next step would be to assess the costs connected to an implementation. That would provide an indication whether the solution can be seen as a promising business case or not. Thereafter the different methods for confirmation that could complement the smart glasses and allow operators to transfer information back to the WMS, needs to be evaluated and the most suitable one selected. Finally, a proof of concept is the final step before an implementation to ensure a working system with required functionality.

6.3 Additional Potentials

One important factor to acknowledge is that there could be major potentials for smart glasses that have not been identified in the report. The authors had smart glasses as they work today as a starting point for the project, instead of the potential features with the technology that is likely to be available within the coming years. With respect to the fast development of the technology and also of the studied processes, the result of the study may soon become outdated. As the thesis does not consider the development of the technology, the value of obtaining knowledge about a possible future practice is not included. Because of the development it may be justified to assess the value of operators and managers obtaining knowledge connected to smart glasses. If operators are gradually introduced to the technology and can participate in the development of a solution, additional ideas can be gathered. That operators start to evaluate the usability of the technology within the different processes they work is hard to achieve with a fully developed solution. This is because it is harder to think outside the box with an imposed complete solution compared to developed versions that are adjusted according to the operator’s feedback. So, if the operator's ideas are to be retained, an in-house development that involves operators is more likely to achieve that.

One of the possibilities that were recognized by both managers and operators during the investigation is the ability to adapt the visual support based on the individual operator. For example, it would be possible to provide support for specific parts for one operator while providing another operator with support during specific times of the day if needed, given that enough data is collected. This would enable customized support to help the operator based on individual need. So, the newly employed that most likely require more support could receive that compared to the more experienced employer that seldom makes any mistakes.

Another application was identified by a Process & IT manager. It was the possibility to use smart glasses to facilitate a more efficient and less resource intensive training of new employees. Training is one of the applications that smart glasses have been used for (Cirulis & Ginters, 2013). Training of employees is costly since it requires a trained operator to stop adding value in the production and instead teach the new employee how to perform the activities within the processes. If this process could be done with the use of smart glasses the possible savings might be substantial. This application of the technology has however many times been connected to the usage of virtual reality rather than augmented reality (Berg & Vance, 2016). Based on the possible savings it might be valid to investigate whether AR or virtual reality would be more sufficient for training of operators and what the corresponding savings might be. The advantage with AR compared to virtual reality is the possibility to train within the current processes and it would allow new operators to gradually receive less support as the learning proceeds.

From the experience based information in both putaway and picking process, the possibility to make the transportation within the warehouse more efficient was seen. Since the majority of the time spent in the putaway and picking process is spent on transport (Bartholdi & Hackman, 2016), the potential is high if time can be saved here. For example if it is possible to make real-time route optimization. However, that would require extensive data gathering and processing which may not be possible today.

6.4 Future Development

As part of the study, the authors held interviews with Volvo LS preferred supplier of warehouse equipment to investigate their perspective on smart glasses. It was stated that there are no current plans to include smart glasses in the product assortment offered. The reason was that no additional productivity gains so far had been seen compared to the voice solution offered, although other possible benefits are being explored. The respondent further elaborated that they have yet to see smart glasses rugged enough for a DC application. However, if benefits are confirmed and if there is a large customer request for the technology may the preferred supplier acquire a smart glass start-up company. The concern regarding the durability of smart glasses for industrial purpose is also mentioned by Volvo LS' WMS partner. This partner has on the account of another customer implemented a WMS interface solution allowing a third party to provide a smart glass solution. The solution is however not implemented on the same WMS software that is used by Volvo LS. For future releases of their WMS software, the company states that a standard application interface may be included to allow customers such as Volvo LS to use for implementation of smart glasses. Other issues that have been brought up are incidents of overheating, insufficient battery capacity and limited processing capability of currently available hardware.

As demonstrated by the environment interactive and three dimensional display capabilities of the Microsoft Hololens, the available technology is rapidly developing. The benefits of allowing information to interact with the environment are evident. It can be more comprehensive and efficient in making the user understand the information (Section 5.3.1). Furthermore, for some applications it allows the communication of information that would be hard to do in any other way (Section 5.3.2). However, there are still issues to be solved if smart glasses are to be used in large industrial areas, such as the ability to identify the environment correctly (Microsoft, 2017a). Any difference between how the smart glasses perceive the environment and how it is would significantly impact information accuracy and in extent performance. For example, if the visualization of product characteristics is incorrectly placed on top of the part to be picked, it could lead to the wrong part being picked. That this issue poses a significant challenge today could be the reason that the current DC smart glass solutions, which the authors have seen to be offered, are using AR with a low level of interaction or attachment to the environment (Evolar, 2014; Ubimax GmbH, 2017; Pcdata BV, 2016; Picavi GmbH, 2016). With that in mind, the full potential of smart glasses is still not realized. Furthermore, other related functionalities may in time be developed. One area which has been recognized during the thesis work is object recognition (Grauman et al., 2011). If it is possible to identify parts and their potential flaws through object recognition through smart glasses, significant benefits could be achieved in returns and quality processes for Volvo LS. The outcome of these processes rely heavily on the product knowledge of the operators (Section 4.2.1), meaning their ability to identify products and decide whether or not the quality level is satisfactory. If the smart glasses can identify the product, several process steps can be removed and corresponding information for decision support can be given directly. The process quality could also be improved with additional support, especially if it is possible to automatically detect damages.

While the thesis has mainly discussed smart glasses, it is important to note that there are other technology areas in development which may affect the potential of smart glasses. The perhaps most obvious is the automation trend. The Boston Consulting Group (2012) recognizes a future potential of improving both quality and productivity by automating warehouse operations. Especially for applications where products are handled in low quantities like individual pieces, as is done in Volvo LS' support DCs. A higher degree of automation implies less manual labor thus less need for smart glass solutions in the regular DC processes. Another technology, which can be found on Gartner's hype cycle 2015, was additive manufacturing (Gartner, 2015). Additive manufacturing is a technology that produce an object by printing a chosen material successive layers based on a three dimensional digital file (Sasson & Johnson, 2016). The technology enable production of only the products needed since the machines can print any part as long as the material and the 3D file is available. This on-demand production removes the need for storage (Weller et al., 2015) and enables economical realization of small batches (Holmström et al., 2010). Because of the possibility to produce small volumes according to demand the technology must be considered as an opportunity for spare parts. Especially for parts that are of high value with infrequent demand the technology can be a solution instead of costly storage. If the low frequent parts could be replaced with additive manufacturing the need for warehousing and with that also the potential for smart glasses would decrease. However, smart glasses could still be seen as a complementing solution enabling efficient handling of frequent parts while additive manufacturing might be the solution for the low frequent parts.

7 CONCLUSION

The purpose of the thesis was to identify and assess the potential of using smart glasses in Volvo LS' DC processes, compared to currently used methods. To fulfill this purpose, processes in both Eskilstuna and Gent DC have been studied. The thesis has fulfilled that purpose through answering the following research questions.

> *RQ1: What performance measures are used to evaluate a DC and how do smart glasses affect those measures?*

The identified performance measures for a DC consist of four dimensions: productivity, quality, flexibility and ergonomics (Chapter 2.2). The first three are commonly used within logistics research while the last measure, ergonomics, was included due to its importance for Volvo LS and to enable the evaluation.

How smart glasses affect the performance measures identified for a DC was stated based on previous research (Chapter 2.3). Smart glasses are competitive and perform at least equally well regarding productivity. Compared to alternative methods, smart glasses enable higher quality. Regarding ergonomics, it was from literature concluded that smart glasses had great potential to reduce the cognitive load for the operators. However, questions linked to the effects of long term use are still unanswered.

> *RQ2: What information is beneficial to communicate with smart glasses in Volvo LS' DCs?*

In the DCs, three different types of information were identified to be used by operators in the processes. These are: received information that operators receive today, transmitted information that operators upload to the system and experience based information, which operators know from previous learning's (Chapter 5.1). For the received information, the performance was deemed to be affected positively but not significantly. Transmitted information is not an applicable information type for smart glasses instead a complementary solution is needed for that information. However to display additional information in the processes, meaning the experience based information, was identified as the main potential for smart glasses. The additional information would function as decision support for the operators. However, it is recognized that adding too much or irrelevant information will have a negative performance effect.

> *RQ3: How could a solution look like and what gains can be derived from an implementation?*

The potential of using smart glasses both in the existing processes (Section 5.2.1) and the potential of using smart glasses if the processes can be changed (Section 5.2.2) was identified. The smart glass solutions with the highest potential were: display additional information in picking (Section 5.3.1) and include sorting in the picking process (Section 5.3.2). The first solution is to display additional information during picking that will allow the operator to pick both with better quality and better ergonomics. The second solution would by providing the shipping container in the beginning of the picking process enable simultaneous picking and packing. Hence, removing the need for sortation between the activities.

Both of the suggestions indicated great savings potential with preliminary estimations of yearly savings of 73 000 SEK for displaying additional information in picking and 214 000 SEK for including sorting in the picking process. These savings are only based on rough calculations and estimations of cost factors and should not by any means be seen as certain, but instead as indications of what could be achieved. However, it is recognized that there are furthermore additional benefits of the solutions which have not been taken into account.

In conclusion, it is recognized that the technology is rapidly developing and that smart glasses hold large potential in the future. Furthermore, by introducing the technology in early stages to employees, overlooked potentials might be discovered. However, it is deemed that the current potential and maturity of smart glasses may not be sufficient to motivate a full-scale implementation of the technology in a DC. Instead, Volvo LS is suggested to do further investigations and a proof of concept. This would allow them to follow the technology development, find new or overlooked potentials and gain knowledge, to prepare Volvo LS for future implementation.

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