



CHALMERS
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Prerequisites for Black Box Picking

Identification of Prerequisites for the Black Box Order Picking Method in Warehousing

Master's thesis in Supply Chain Management

LINN AMBRING
ADAM JÄDERQVIST

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
DIVISION OF SUPPLY AND OPERATIONS MANAGEMENT

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
www.chalmers.se
Report No. E2023:078

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Report no. E2023:078
Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

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SUMMARY

Consolidation of orders is a time-consuming process in a warehouse. The company of collaboration for this master's thesis, DB Schenker Logistics, wants to eliminate the process of consolidation by transitioning to the black box order picking method. Black box picking is a version of pick-and-pass where goods are picked in secondary warehouse zones before they are placed, and later picked, in a main zone. DB Schenker Logistics needs to understand what prerequisites are important for a successful black box system. The aim of this master's thesis is therefore to identify the prerequisites needed for a black box picking system in a warehouse. Thereby, the thesis will provide support for warehouse designers to facilitate the implementation of a black box system. Data collection for the master's thesis was conducted using a literature review, visits to DB Schenker Logistics' warehouses, and visits to four case companies' warehouses. During the warehouse visits, interviews and observations took place. Interviews were also performed with personnel working at DB Schenker Logistics. The literature review was used to develop a framework for assessing prerequisites for black box picking, which thereafter was used for data analysis of the collected empirical data. The framework focused on the three categories of system factors, product and order factors, and inventory factors, which were then further broken down into several subfactors. The identified factors were classified as prerequisites, simplifying but not necessary, and not prerequisites. The findings have implications for DB Schenker Logistics and for warehouses in general. For DB Schenker Logistics, the framework can be used to evaluate if prerequisites exist for black box picking, in order to avoid consolidation in the warehouse. Furthermore, the developed framework can be used by warehouse designers in general to assess if black box picking is suitable for application in a certain warehouse setting.

Keywords: BLACK BOX PICKING, PICK-AND-PASS, PICKING METHODS, ORDER PICKING, WAREHOUSE DESIGN

Acknowledgement

The master's thesis was written in collaboration with DB Schenker Logistics AB in Landvetter, Gothenburg and was a part of the Supply Chain Management master's programme at Chalmers University of Technology.

We would like to express our deepest appreciation to all those who have supported us in the writing of our master's thesis. First and foremost, we would like to thank our supervisor at Chalmers University of Technology, Robin Hanson, for his encouragement and support during our thesis process.

Furthermore, we are grateful to, Tim Maalsnes, our supervisor at Schenker, for his valuable guidance, insightful feedback, and constant encouragement throughout the entire process. We would also like to thank Charlotta Larsjö for bearing with us on our trip to Stockholm, and for her valuable insights during our interview. We are also grateful for the insights Tobias Karlsson provided during our interview with him. Another thank you for all other personnel at Schenker, which has provided answers to all of our questions.

Finally, we would like to thank all of the companies which we got to visit and interviewed, without you, this master's thesis would not have been possible.

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Abbreviations

AGVs	Automated Guided Vehicles
AS	AutoStore
AS/RS	Automated Storage and Retrieval System
SKU	Stock-keeping unit
WMS	Warehouse Management System

1. Introduction

The following chapter presents a background to understand the issue and aim of the master's thesis. The background provides an overview of logistics, warehousing, and a version of the order picking method of pick-and-pass, by DB Schenker Logistics (hereby referred to as Schenker) called black box picking. The aim of the master's thesis is then presented and lastly, the limitations are presented.

1.1. Background

Jonsson and Mattsson (2016) explain that the material flow of a logistics system consists of movement, handling, and storage of goods. The warehouse's main functions are to keep inventory for a period of time and forward goods to another actor in the network according to Pfohl (2022).

Rouwenhorst et al. (2000) describe the flow of items through a warehouse and that it can be split into different processes. The first process is the *receiving* of goods which occurs when an item arrives at the warehouse. The next process is the *storage* of items, which is when items are placed in a storage location, which can consist of a reserved area and a forward area (Rouwenhorst et al., 2000). The third process in the flow of goods in a warehouse is *order picking* and it is when items are retrieved from respective storage locations (Rouwenhorst et al., 2000). According to Goetschalckx and Ashayeri (1989, p. 99), order picking could be defined as “...*the activity by which a small number of goods is extracted from a warehousing system to satisfy a number of independent customer orders*”. Rouwenhorst et al. (2000) explain that order picking could either be done manually or through automation, and it is in this step sorting and/or consolidation occur. The last step of the flow of items in a warehouse is *shipping*, where orders are controlled, packed and loaded into vehicles (Rouwenhorst et al., 2000).

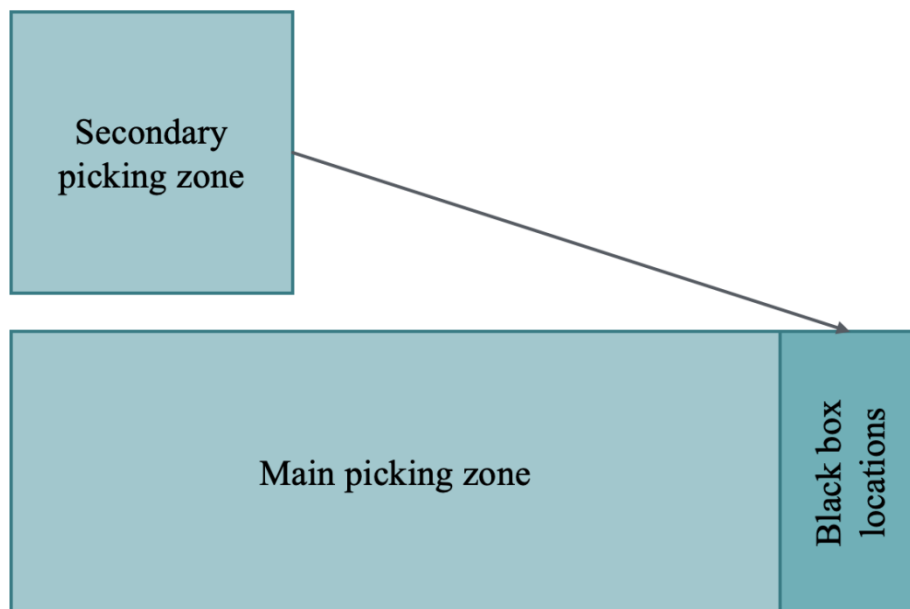
As explained by Rouwenhorst et al. (2000), consolidation and sorting take place in the third process which is order picking. Hall (1987, p. 57) explains consolidation as “*the process of combining different items, produced and used at different locations and different times, into single vehicle loads.*”. Inventory consolidation is the simplest form of consolidation and is when items produced at different times are stored and then transported in the same load. Consolidation can also be in the form of terminal consolidation when items from different origins are brought to one location, where they are sorted and loaded onto new vehicles, and then brought to different locations. One advantage of consolidation mentioned is lower transportation costs since the fixed cost stemming from the transportation then is divided into multiple items. Downsides to consolidation include higher inventory costs, since items need to be stored for a longer time period, longer routes, longer travel time and added handling costs (Hall, 1987). Boysen et al. (2019) explain that depending on the order picking method, orders might have to be consolidated before leaving the warehouse. A customer order can contain items from several areas of the warehouse that are picked by different order pickers. To be able to send a complete order, items from the various areas in the warehouse need to be consolidated into a single package (Boysen et al., 2019).

Partikh and Meller (2008) conclude that, by using progressive zone picking, it is possible to avoid having a sorting system. Thus, by using progressive zone picking, the consolidation process could be eliminated. Pan et al. (2015) explain that progressive zoning is another name for pick-and-pass. When picking according to pick-and-pass, the picking area is divided into zones where each order picker picks the requested stock keeping units (SKUs) of the order in their respective area, and then another order picker continues the picking of the order in another zone (Pan et al., 2015). Dallari et al. (2009) explain that since all the items of a single order are placed in the correct container during the picking, the sortation process can be eliminated with pick-and-pass. Pick-and-pass can be beneficial when working with orders of smaller sizes and smaller products (Dallari et al., 2009). Yang et al. (2022) state that the pick-and-pass picking method can result in increased efficiency.

Black box picking, a version of pick-and-pass is of focus for this master’s thesis. Black box picking is operated in a warehouse with one main picking zone, and one or more secondary picking zones. The order picking in the secondary zones is usually initiated and completed before the picking in the main zone begins. The picked items in the secondary zones are placed

in a container or a carton which is then allocated a new shelf location in the main zone. A black box location is a certain area of the main picking zone where goods from the secondary zones are stored, once the picking is completed in the secondary zones. When the order picking in the main zone begins, the containers with items from the secondary zones are picked up by the order picker in the main zone. The method of black box picking is visualized in figure 1. The reason behind the name ‘black box picking’ is that the goods from the secondary picking zones could be placed in a carton that is later closed, hence a black box.

Figure 1. *Visualization of the black box picking method.*



Schenker is a third-party logistics company, supplying its customers with logistics services ranging from the receiving of goods to the transportation of packages, and also handling of returns. The company’s Swedish branch has eight warehouses in total which are located in Gothenburg, Stockholm, Jönköping, and Nässjö.

Schenker uses consolidation for some of their customers, while not consolidating at all and sending items in separate packages for other customers. The process of consolidation is considered resource-consuming because of the double handling having to take place. Schenker therefore wants to investigate which prerequisites are needed to transition from consolidation to black box picking.

1.2. Aim

The aim of the master's thesis is to identify the prerequisites needed for a black box picking system in a warehouse. Hence, the thesis will provide support for warehouse designers to facilitate the implementation of a black box system.

1.3. Limitations

The master's thesis will not investigate actual improvements in performance and change in output caused by a transition from consolidation to black box picking. The advantages and disadvantages of the two different ways of picking will not be included in the thesis. Since the main objective is to facilitate the transition from consolidation to black box picking at Schenker, the implications of the thesis mainly focus on Schenker as a company.

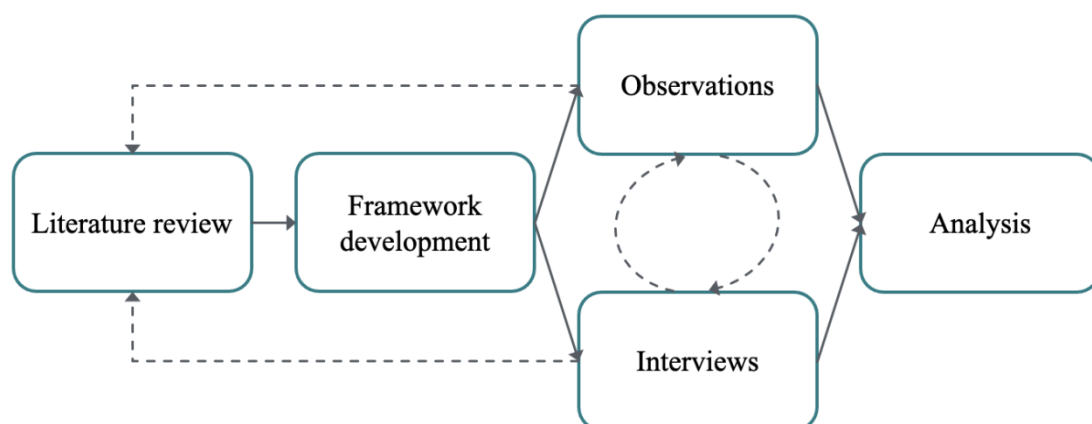
2. Method

In the following chapter, the research methodology used for the master's thesis is presented. The overall research process is initially described concerning how the literature review, observations, interviews, and data analysis were conducted. The chapter then further describes the process of data collection and the methodology used for interviews and observations. The chapter continues with a description of the methodology used in the analysis of the data collected. Reliability and validity of the data collection and data analysis are then discussed in order to ensure high reliability and validity of the master's thesis. Lastly, ethical considerations are considered.

2.1. Research process

The research process started with a literature review, to gain basic knowledge about warehousing as a whole, but also to deepen the knowledge about existing studies regarding pick-and-pass. The literature review was also used to provide a background to the report, and to serve as a basis for the development of a framework for assessing prerequisites for black box picking. After the literature review was performed, both observations and interviews were conducted in parallel. The input from the observations was used during the interviews and vice versa. When previously unknown information was introduced during the observations and interviews, additional literature reviews were conducted. The input from the observations and interviews was later combined and analyzed to identify the prerequisites needed for a black box system in a warehouse. The research process is visualized in figure 2.

Figure 2. *The research process and its different segments.*



The observations and interviews were conducted at three companies currently using black box picking as an order picking method. An observation and interview were also performed at another company not currently using pick-and-pass or black box picking.

The persons being interviewed at Schenker were working at the departments “*Solution Design*” (SD) and “*Operational Excellence*” (OpEx). SD is responsible for the development of picking processes when introducing new customers to the warehouse, and OpEx is working with the implementation of new customers as well as the development of current processes. Both these departments had a deep knowledge of warehouse design, current picking processes and existing tools, which was of great help when investigating the need for a black box picking system.

2.2. Data collection

The data collection describes the different methods used, namely the interviews, observations and case company visits.

2.2.1. Interviews

During the study, semi-structured interviews were used to collect qualitative data, both when gathering data about Schenker’s operations, but also when collecting data from other companies describing their picking processes. There were two interviewers at all times and the interviews were held in Swedish since all interviewees were Swedish speaking.

Bell et al. (2019) describe a semi-structured interview as when the interviewer has general questions in the form of an interview schedule, but can vary in which order the questions are asked. The interviewer is also able to ask follow-up questions in response to what the respondent answers (Bell et al., 2019). The interviews during the data collection were semi-structured, with some prepared questions, but also with a possibility to ask about subjects arising from the interview.

An interview inquiry has seven stages, Brinkmann and Kvale (2015) claim. The first stage is thematizing, where the purpose of the interview is formulated as well as the theme that will be looked into. Designing is the second stage, and during this stage, the study is planned. During

the third stage, interviewing, the actual interviews are conducted according to an interview guide. After the interviewing has taken place, it is time to transcribe the interview material to prepare for the fifth stage; analyzing. In the sixth stage, the interview is verified through validity, reliability and generalizability. The last stage is reporting and consists of the study findings being communicated (Brinkmann & Kvale, 2015).

Both interviews with Schenker were conducted over Microsoft Teams. Before the interviews, questions were formulated, which later were used as an interview guide during the interviews. The formulated questions can be found in appendix A, for the interview with Tobias Karlsson, and in appendix B for the interview with Charlotta Larsjö. Both interviews were recorded. The interviews are listed in table 1.

Table 1. *Overview of conducted interviews with people working at Schenker.*

Date	Name	Position
28/4	Tobias Karlsson	Solution Design Specialist
5/5	Charlotta Larsjö	Operational Excellence Specialist

2.2.2. Observations

Observations were used to investigate pick-and-pass processes, and specifically black box picking at other warehouses than Schenker’s, which could be used at Schenker’s warehouses in the future.

Patel and Davidson (2003) explain that observation is a useful method when collecting data in natural situations. Bell et al. (2019) agree with Patel and Davidson (2003) and mention structured, or systematic, observations as a useful way of observing people’s behavior directly. When conducting a structured observation, the researcher records behavior according to certain predefined rules. It is important that those rules are as specific as possible to enable the observer to distinguish the crucial behavioral aspects taking place (Bell et al., 2019). Another way of

performing an observation mentioned by Patel and Davidson (2019) is through an unstructured observation, which can be used for exploring and gaining as much information as possible. Observations can, according to Bell et al. (2019), be performed through incidents, short periods of time and longer time periods. When conducting the data collection of the master's thesis, the observations were unstructured and performed over short time periods.

The ones observing the situation of interest can act in different ways, Patel and Davidson (2003) explain. The observer could either be participating or non-participating as well as known or unknown to the one being observed (Patel & Davidson, 2003). According to Hennink et al. (2011), the non-participating observation enables the observer to get a good overview of the activities taking place, since it is possible to see the bigger picture. In the report, the observer was always non-participating. The observers were unknown during all of the observations.

While conducting the observations, Hennink et al. (2011) highlights the importance of taking field notes. Short notes should be taken continuously during the observations, and later elaborated on. It is of importance to note the date, time and place for the observations, and to improve the detail of the notes, drawings can be used (Hennink et al., 2011). To ensure all important data was captured during the observations, notes were taken continuously. Drawings were used during some of the observations, to ease the recall of the warehouse design.

2.2.3. Case companies visits

For the data collection for the report, the authors visited four warehouses, which can be seen in table 2. During the visit to the warehouse of case company 1, the authors were guided by the warehouse manager and the operations manager. First, the warehouse and the warehouse operations were observed, and then an interview was conducted, to gain further insight about essential prerequisites for black box picking. For case company 2, the visit started with a short introduction to the company and its WMS, by two of the company's personnel working in the IT department, and the warehouse's operations manager. After the introduction, an observation was conducted, and after that, an interview was conducted, where another employee from the IT department joined. During the visit to case company 3, the logistics manager first introduced the authors to the company, and then, the warehouse was observed. During the visit to case company 4, the production manager, as well as an expert on AutoStore (AS) guided the authors

in the warehouse. During all of the observations for all of the case companies, unstructured interviews were conducted at the same time as the walk-through. The interview guide used at the four case companies is found in appendix C.

Table 2. *Overview of case company visits.*

Date	Case company	Interviewee
22/3	4	Production manager and AS expert
28/3	1	IT personnel and operations manager
4/4	3	Logistics manager
5/4	2	Warehouse manager and operations manager

2.3. Data analysis

In order to analyze the collected qualitative data, the method of grounded theory was used, as explained by Bell et al. (2019). A number of examples of tools that can be used within grounded theory include theoretical sampling, coding, theoretical saturation, and constant comparison. What data to be gathered was determined by the insights of previously gathered data by the authors, in line with theoretical sampling (Bell et al., 2019). Data gathered from observations and interviews could be used as input to determine the structure for new observations and interviews, e.g., new interview questions. By looking at the data already collected, the authors of this master's thesis therefore decided on what type of data was needed for the upcoming data collection. Furthermore, Bell et al. (2019) describe coding as a way of organizing and naming the gathered data based on its components. In the master's thesis, the data gathered was continuously coded in order to organize and compare what has been collected. For the interviews, coding meant that similar statements of the interviewees were grouped, or coded, together. In the case of this master's thesis, one example was when multiple interviewees mentioned the need of a WMS, those answers were then grouped together. During the observations, the coding was performed by grouping different observed characteristics

together, for example, the same storage systems used at different warehouses. The coding enabled analysis since it was possible to find patterns between different data sources. Lastly, the tool of constant comparison was used in the thesis by continuously comparing the data from e.g., interviews to the already coded and gathered data (Bell et al., 2019). The comparison was an ongoing process for the authors where new data collected from interviews and observations were put into comparison and relation to the previously collected data and insights from previous interviews and observations.

2.4. Reliability and validity

Connected to reliability, Bell et al. (2019) discuss intra-observer consistency and inter-observer consistency as two parts of reliability when conducting observations. Intra-observer consistency is when a person might be inconsistent in the measurements due to different factors (Bell et al., 2019). During the observations, the aspiration was to always have two persons taking notes to avoid intra-observer consistency. However, to ensure all relevant questions were asked, only one person ended up taking notes. Bell et al. (2019) further explain that inter-observer consistency is when there are inconsistencies in the measuring between the people conducting the observations (Bell et al., 2019). For the master's thesis, however, this inter-observer consistency was minimized by the authors by conducting the observations together.

Concerning the validity, Bell et al. (2019) mention two concerns to be taken into consideration. Firstly, what is observed needs to be the same as what is actually supposed to be observed and evaluated (Bell et al., 2019). To ensure the validity of the observations, the results from the observations were continuously evaluated to ensure that the correct observations were being made. Analysis of the collected data therefore began after the first interview and observation, instead of after all interviews and observations were finished. Secondly, Bell et al. (2019) state that observation might make workers act differently. Since the master's thesis did not concern the workers' behavior, but the picking process overall, the problem of workers acting differently is not relevant.

Silverman (2010) describes that after every data collection, categorization and coding of collected data must be done in the same way, in order to achieve reliability. To ensure the reliability of the data analysis and categorization in the master's thesis, the data collection and

categorization of the collected data were always made by the two authors. The approach aimed to minimize any differences when categorizing data from different interviews and observations in order to achieve high reliability.

To achieve validity in the analysis of the collected data, methods from Silverman (2010) were used. Firstly, the refutability principle was used, meaning that if certain conclusions are derived from collected data, these conclusions need to be tested further and see if these conclusions are possible to disprove (Silverman, 2010). During the data collection, findings at one case company were compared to findings at other case companies to find differences and similarities. The results from the case companies were also kept in mind when the authors formulated the interview questions for the interviewees, in order to test earlier conclusions. Secondly, the deviant case analysis presented by Silverman (2010) was used. The method proposes that information that seems to stand out or contradict the majority of the data should be further investigated to understand the reasons behind it (Silverman, 2010). The authors of this master's thesis had an aspiration to further analyze data that stood out, but since there were not any major divergent data, it was not possible.

2.5. Ethical considerations

Bell et al. (2019) reference Diener and Crandall (1978) when they bring up the four main areas of ethical principles as harm to participants, lack of informed consent, invasion of privacy, and deception. The avoidance of harm includes physical harm, harm to the development or self-esteem of the participants, as well as harm to future employment or career prospects (Diner & Crandall, 1978, as referenced in Bell et al., 2019). During the data collection for the master's thesis, it was important to consider the possible harm to future employment or career prospects, especially during the observations.

Informed consent is described by Bell et al. (2019) as the participants being given enough information about the study to ensure they can make an informed decision if they want to participate or not. The participants should also be informed if observation techniques or equipment for recording are used (Bell et al., 2019). During the interviews, the participants were able to make an informed decision if they wanted to participate or not. However, during

the observations, an ethical dilemma arose since the participants were being observed at their workplace and therefore might have felt forced to participate.

It is important to protect the participant's privacy according to Bell et al. (2019). Privacy is linked to informed consent in the sense that the participants need to know what is expected from his or her involvement in the study. It is also important to accept that the participants might not want to answer all questions asked. In regards to preventing deception, it is crucial to correctly describe the research (Bell et al., 2019). Regarding those two ethical aspects, it was important to accept that a participant's previous consent could be withdrawn, as well as provide a precise description of the research and data collection process.

3. Theoretical background

Vanheusden et al. (2022) identify nineteen practical factors influencing the performance of order picking and categorizes them into; system, human, product and order, as well as inventory. The categories system, product and order, and inventory act as a base for the master's thesis division of factors and as a base for the theory presented in the following chapter. However, since the master's thesis is not focused on human aspects, no theory regarding human aspects of picking is brought up, thus Vanheusden et al. (2022)'s human category is not used. Considering the master's thesis limitation regarding not focusing on output, but on prerequisites for the order picking method black box picking, all factors brought up by Vanheusden et al. (2022) will not be brought up. Instead, factors brought up by Rushton et al. (2021), Ghiani et al. (2013), Baudin (2004), de Koster et al. (2007), and Brynzér and Johansson (1995) will also be included. Based on the factors presented in the theoretical background, a framework is constructed. The framework serves, together with the collected empirical data, as a basis for the analysis and discussion of the master's thesis.

3.1. System

Vanheusden et al. (2022) describe system factors as factors concerning the current warehouse layout as well as currently available resources and safety regulations in the warehouse. In the short term, system factors are difficult to change because of decisions of a strategic nature about system selection and design of the layout (Vanheusden et al., 2022). The following chapter includes warehouse management system, identification system, zoning, material handling equipment, storage systems, and support systems for the order pickers. These areas were categorized as system factors since they concern the warehouse layout as well as currently available resources.

3.1.1. Warehouse management system (WMS)

Both Accorsi et al. (2013) and Sharp (2007) explain that one of the main functions of the warehouse management system (WMS) is to track the flow through the warehouse. Rushton et al. (2021) state that the WMS can support multiple warehouse operations such as the receiving of goods, order picking, order sortation, and monitoring stock levels. Depending on the

company and types of products, certain functions can be added or adapted to the WMS e.g., the monitoring of expiration dates could be particularly essential for perishable products. Rushton et al. (2021) continue explaining that the WMS receives information from several sources including the scanning of barcodes, which is further described in chapter 3.1.6. A WMS has the possibility to improve the performance of the warehouse in several metrics such as efficiency and customer service (Rushton et al., 2021).

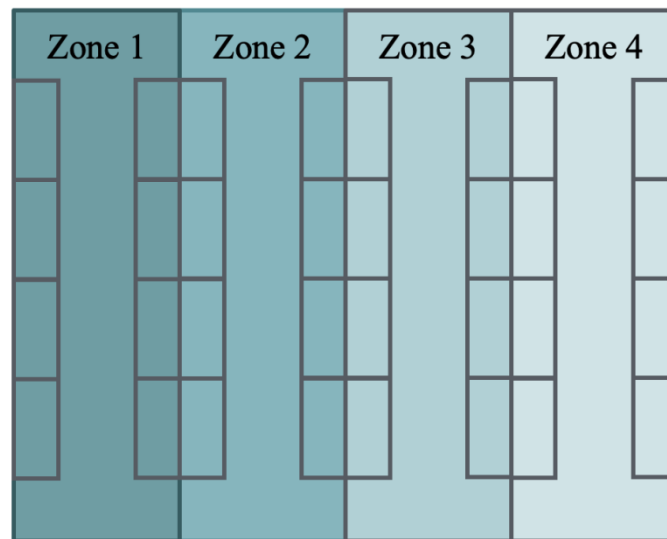
3.1.2. Identification system

Ghiani et al. (2013) explain that for computerized warehouse management, it is crucial to codify packages. The identification codes can be scanned by automatic devices. Identification systems include barcodes, which are a transformation of an alphanumeric or numeric code to vertical bars and spaces. To read the barcodes, either optical or laser scanners can be used. Logistic labels are another way of codifying packages, and the information is displayed through barcodes, characters, numbers and other graphic elements (Ghiani et al., 2013).

3.1.3. Zoning

De Koster et al. (2007) explain that zoning means that the pickers are responsible for picking in a specific area of the warehouse, i.e., their picking zone. A complete order might therefore need to be picked by more than one picker in more than one zone (de Koster et al., 2007). The separation of picking zones is visualized in figure 3. According to Melacini et al. (2010), it is crucial to define the picking zone's number and size to minimize the total costs for order picking. When using fewer but larger picking zones, the travel time will be longer. However, smaller but several picking zones decrease the use of pickers while increasing the costs per picking station (Melacini et al., 2010). I.e. the utilization of the pickers could be decreased if too many zones are used, which leads to the cost per picking station being distributed over a smaller amount of orders. According to Frazelle (2016), zoning provides benefits such as reduced traffic in the picking zone, shorter distances to move for the pickers, the possibility to measure the efficiency in different zones, and the pickers getting used to the items in their particular picking area.

Figure 3. *Visualization of a warehouse divided into different picking zones where each zone corresponds to a picking aisle.*



3.1.4. Material Handling Equipment

Baudin (2004) explains that the different means of internal transportation are forklifts, pallet jacks, push carts, tuggers and trains of tow carts, conveyors, and automatic guided vehicles (AGVs). The forklift is according to Richards (2021) used in a warehouse for the movement and transportation of palletized storage. The forklift is controlled by personnel in the warehouse and is powered by batteries (Richards, 2021). Forklifts are, according to Kay (2012), used for material movement when no area restrictions exist while the point of start and finish is not predefined.

Baudin (2004) states that pallet jacks can be used for transporting goods over shorter distances in the warehouse. The pallet jacks can have a variety of different applications but are limited by their inability of larger vertical lifts. Push carts are manually controlled by warehouse personnel and allow for flexible movements. The push carts can be useful when working with smaller unit loads such as tote bins. Tuggers and trains of tow carts are several trolleys connected together which allows for transportation of larger amounts of products in the warehouse. The train of tow carts can be used for frequently repeated deliveries in the warehouse (Baudin, 2004).

Kay (2012) describes that conveyors are used for transportation of materials between two predefined places over a fixed path. Since the investment in conveyors is quite high, the volume of the flow must be big enough to legitimize its use. Cranes are used for the movement inside a defined area with the possibility to handle loads of high variety in regards to weight and shape. Cranes are a cheaper and more flexible alternative to conveyor belts (Kay, 2012).

AGVs are, as explained by Richards (2021), useful for transportation of products inside the warehouse. The AGVs can among other solutions be controlled using wires laid out on the floor to reach the correct destination for despatch. However, there are drawbacks to the system such as need for adaptations in the warehouse, and costs (Richards, 2021).

3.1.5. Storage systems

There are different ways of storing goods in a warehouse and for palletized storage, Rushton et al. (2021) bring up multiple storage systems including block stacking, drive-in and drive-through racking, push-back racking, hanging garment storage, as well as automated storage and retrieval systems (AS/RSs). Another storage system brought up by Rudd (2019) is mezzanine flooring.

Block Stacking is, according to Rushton et al. (2021) when pallets are placed on top of each other without any racking equipment. Usually, there is a fixed depth when arranging block stacks, and they are arranged at a 90-degree angle to the aisle. Because of the block stacks nature, the newest goods are used first, making it a last-in first-out system.

Kay (2012) describes different pallet storage systems. The most popular storage rack type is the selective pallet rack, which is when load-supporting beams are holding up pallets. There are two types of selective pallet racks, single-deep rack, and double-deep rack, which either has the possibility of storing one, or two, pallets per position. For drive-in racking and drive-through racking, loads are stored on rails that are joined to upright beams. The difference between those two storage types is that the drive-through racking is open at both ends which enables access from both ends, while drive-in racking only provides access from one opening. The push-based racking and the flow-through both use a roller conveyor and gravity for the movement of loads. The difference between the push-based racking and the flow-through

racking is from where the goods are loaded, where the push-based is loaded from the front, and the flow-through is loaded from the back. Flow-through racks can either be used for pallets, called pallet-flow racks, or for cartons, called carton-flow racks. Another option for storage of non-palletized items is bin shelving, where the items are placed either in cartons or bins, or directly on shelves (Kay, 2012).

Rushton et al. (2021) explain hanging garment storage as a specialist system for handling garments on hangers. There are both manual and automated hanging garment storage, where the automated ones are based on an overhead conveyor system. The advantage of hanging garment storage is that the garments can be stored hanging, i.e. they do not need to be folded (Rushton et al., 2021).

In an AS/RS, Baudin (2004) explains that operators either input materials into the system, or request materials which are then unloaded. The system decides the storage location and movement of goods, making it faster than a manual storage system. Richards (2021) explains that the AS is a goods-to-picker storage system where robots deliver boxes with products to a stationary picker. The boxes are stored in a large network of stacks of boxes that are retrieved by robots (Richards, 2021).

Rudd (2019) explains that a mezzanine floor originally was a floor between the building's main floors, but now, a mezzanine floor is a steel floor that is semi-permanent and used for better utilization of vertical space. It is possible for operators to walk up and down to a mezzanine, but for goods to be transported between the mezzanine and the floor space, either a goods lift or conveyors will have to be installed (Rudd, 2019).

3.1.6. Support systems for the order picker

Battini et al. (2015) explain that there exist several different picking aids that support the order pickers in the picking process. According to Rushton et al. (2021), the order picking can be conducted using pick-by paper. With pick-by-paper, the order picker receives all necessary information on what products to pick and where to find them on a piece of paper. Using that paper, all required products are picked (Rushton et al., 2021). One alternative picking aid is the barcode scanner, which, as explained by Battini et al. (2015) registers a barcode located either

at the picking spot or directly at the required item. The barcode scanner confirms that the requested item has been picked, and can also provide information on what the order picker should pick (Battini et al., 2015).

Another alternative presented by Battini et al. (2015) is the pick-by-voice system, where picking information is sent to the order picker in e.g., an earpiece. The order picker then confirms the pick by speaking back to the system, before receiving information on another order to pick. The order picker can also be guided by a pick-by-light system. In the pick-by-light system, a light at the requested item's location shows the order picker what to pick. The pick-by-light system can be combined with other support systems such as a pick-by-paper and a barcode scanner (Battini et al., 2015).

3.2. Product and order

Vanheusden et al. (2022) present the category of product and order as factors concerning the characteristics of the products picked and characteristics of the orders, such as returns from customers and promised delivery times. An example of product and order factors is product characteristics. The following subchapter brings up product characteristics, order characteristics and unit loads.

3.2.1. Product characteristics

Rushton et al. (2021) discuss several product characteristics, both concerning the physical properties, but also properties which require special consideration such as dangerous goods, perishable products, high-value products, and fragile products. An example of perishable products provided by Rushton et al. (2021) is food items that need to be stored at cool temperatures. Adaptations may therefore be needed for the storing and handling of perishable products. Products such as valuable electronics are examples of high-value products which need certain considerations when handling. Fragile products are another category that needs to be managed in a certain way to avoid damage (Rushton et al., 2021). Chabot et al. (2017) state that to avoid damages, fragile items need to be stored above other items in the warehouse. Žulj et al. (2018, p.338) explain precedence constraints as when “*the order-picking sequence is partially predetermined due to fragility restrictions, stackability, shape, size, and preferred*

unloading sequence”. If precedence constraints are not complied with during the design of the order picking process, it can lead to additional handling when the items need to be repacked (Žulj et al., 2018).

Examples of dangerous goods described by Rushton et al. (2021) include explosives, flammable gasses, liquids and solids, as well as toxic, corrosive and oxidizing substances. Because of the regulations regarding dangerous goods, the warehouse design needs to be adapted. Examples of those adaptations include separate buildings, or separate zones, which can be isolated in case of emergency, banded storage areas and secured areas with limited access. The dangerous goods also need specific packaging where the goods are labeled as hazardous (Rushton et al., 2021).

3.2.2. Order characteristics

According to Mirzaei (2022) to reduce operational time and costs, it is important for managers to consider the customer order profile, and especially the order size, turnover frequency and correlation of products.

Onal et al. (2023) mention that the probability of creating pick lists using one or two neighboring aisles is increased with high picking volumes. Brynzér and Johansson (1995) describe factors affecting picking efficiency as batching policy, i.e. the mix of orders in a batch, picking policy, i.e. in which order the items will be picked, and storage policy, i.e. where the items are stored. Having a suitable batching policy occurs when multiple picking orders are grouped and picked together, since it reduces the travel distance and thus the picking times. Geographical grouping, i.e. using similar picking information for components in the same group, is another way of improving the order picking (Brynzér & Johansson, 1995).

3.2.3. Unit load

Rushton et al. (2021) explain that pallets are the most used unit load in warehouses, and they are made from either wood, plastics or fibreboard. The most used size for pallets in Europe is the EUR-pallet which measures 1.2×0.8 meters, and the pallets can be either two-way or four-way entry pallets depending on if the forks of a truck can enter the pallet in either two or four

ways (Rushton et al., 2021). Advantages of pallets over primary and secondary packages, Ghiani et al. (2013) explains is the possibility to have an increased weight and volume in the same space.

Cage pallets are according to Rushton et al. (2021) a pallet with walls that allows for storing of products that would be difficult to store with another unit load, e.g., odd-sized products. Cage pallets are a type of stillage, which normally means a unit load constructed out of metal. The cage pallets can be used for products with different shapes that would not be possible to stack on a EUR-pallet (Rushton et al., 2021).

Rushton et al. (2021) explain that dollies can be used to store other unit loads on top of their flat surface. Wheels are attached to the dollies which allow for movement (Rushton et al., 2021). The use of tote bins for storage is another unit load described by Rushton et al. (2021). The tote bins are suitable for products of smaller sizes and the bins are usually constructed in plastic. Intermediate bulk containers are, according to Rushton et al. (2021), generally suitable for handling of fluids and are possible to handle with a forklift. Roll cages are explained by Rushton et al. (2021) as a cage with wheels on the bottom which allows the roll cage to be moved around. The roll cages are often made out of metal (Rushton et al., 2021).

3.3. Inventory

Inventory factors concern, according to Vanheusden et al. (2022), what products are stored, as well as where and how the products are stored. The following chapter focuses on different storage assignments.

3.3.1. Storage assignment

The goods in a warehouse could either be placed by dynamically allocated slots for items heavily used, or by using dedicated zones for high-running items, Baudin (2004) mentions. De Koster et al. (2007) explain that dedicated storage is when a product is stored at a specific position that does not change. By using a dedicated zone instead of dynamically allocated slots, Baudin (2004) concludes that the traffic inside the warehouse for that specific product could be decreased, while simplifying the storage and retrieval of other items. It is often advantageous

to combine dynamically allocated slots with dedicated zones by placing frequently used items in small quantities in fixed storage locations, and the other goods in dynamically allocated ones (Baudin, 2004).

3.4. Framework for identification of prerequisites for black box picking

In the following chapter, a framework is constructed to identify what prerequisites are needed when implementing black box order picking. The framework provided by Vanheusden et al. (2022) focuses on factors that impact order picking performance, and not prerequisites for a black box picking implementation. However, the overall structure of the framework presented by Vanheusden et al. (2022) covers several important areas of warehouse operations and is therefore used for the master's thesis. The framework by Vanheusden et al. (2022) is adapted in this chapter to better fit prerequisites for a black box system. The system, product and order, and inventory factors are used as an overall structure for the framework, but new sub-categories from the theoretical background are added in order to align with the aim of this master's thesis. The constructed framework is illustrated in table 3.

Table 3. Framework used to identify prerequisites for a successful black box picking implementation.

Categories	Factors	Subfactors
System	WMS	
	Identification system	
	Zoning	
	MHE	<i>Forklift Pallet jacks Push carts Tuggers and trains of tow carts Conveyors Cranes AGVs</i>
	Storage systems	<i>Block stacking Selective pallet rack Drive-in and drive-through racking Push-back racking Flow-through racking Hanging garment storage AS/RSs Mezzanine floor</i>
	Support systems for the order picker	<i>Pick-by-paper Barcode scanner Pick-by voice Pick-by light</i>
Product and order	Product characteristics	<i>Perishability High-value goods Precedence constraints Dangerous goods</i>
	Order characteristics	<i>Order size Order volume</i>
	Unit loads	<i>EUR-pallets Cage pallets Dollies Tote bins Intermediate bulk containers Roll cages</i>
Inventory	Storage assignment	<i>Dynamically allocated Dedicated zones</i>

4. Empirical data

In the following chapter, the results from the empirical data collection are presented. Observations and interviews from four different case companies' warehouses are summarized, as well as interviews that have been conducted at Schenker.

4.1. Case company 1

Case company 1 (hereby referred to as CC1) is a supplier of medical equipment and consumable products using an externally supplied WMS.

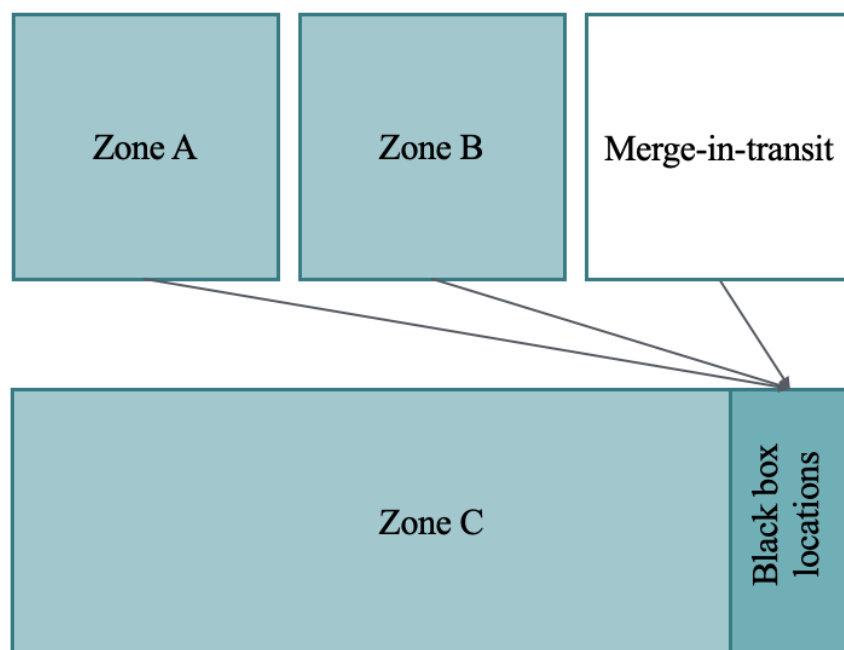
CC1 uses three different zones, zone A, B and C, where the main zone is referred to as C. Zone C contains selective racking, with some regular shelves for pallets, both for smaller pallets, but also for high pallets. The warehouse also has an area using smaller compartments with carton-flow racks in three sizes. In zone C, the picking is performed manually using forklifts by pickers using pick-by-voice. The picking occurs from a maximum of three levels, but only two if high pallet picking is being used. Behind the forklifts, there are tow carts, and when the goods are picked, they are then placed on those carts. The picking locations are mainly fixed, but for goods that are batch handled, dynamic locations are used. In zone C, there is also a storage room for dangerous goods.

Zone A is a smaller picking zone, and here, goods needing to be handled under specific circumstances are stored. Zone A uses batch picking which can be performed in a group. In zone B, smaller goods are stored on a mezzanine on shelves. Here, cartons are placed on a conveyor belt, and the pickers are picking multiple orders simultaneously. When the orders in zone A and B are finished, they are placed in a new picking location situated in the flow racks in zone C. The new picking location is shown in figure 4 as black box locations.

When receiving goods in the inbound flow, the goods are separated into two flows, goods stored in the warehouse and merge-in-transit. The merge-in-transit goods are then transported to the same zone as the goods from zone A and B, namely the rolling trays in zone C.

The pickers enter the area of rolling trays in zone C at the end of the picking round, where they pick the goods from zone A, B and/or merge-in-transit and put them onto the carts. The WMS calculates the size of the goods to ensure that everything fits onto the cart. The picked items from zone A and B are thereafter passed on to the order pickers in zone C, in line with a black box picking system. The order has then been completed, and the carts are placed in an outbound area. The flow through the different zones is visualized in figure 4.

Figure 4. *The flow from zone A and B as well as merge-in-transit to a new picking location in Zone C.*



After conducting an interview with the warehouse manager and multiple IT specialists at the company, it became clear that, for black box picking to work, it is important with takt time. The reasoning behind black box picking for CC1 is that everyone can pick at their own speed even though all of the areas are not as fast as each other. To ensure a smooth process, CC1 uses different start times for the picking based on the departure time. It is important to shorten the time that the items are placed in the designated black box location to ensure the shelves are not filled. CC1 argues that the black box system is especially beneficial if the shipping area is limited and when refrigerated goods are required to be picked as late as possible. When the company decided to implement black box picking it was not yet supported by the external

WMS. The black box picking functionality in the WMS was therefore implemented as a custom-made functionality by the WMS provider to CC1.

4.2. Case company 2

Case company 2 (hereby referred to as CC2) is a wholesaler for restaurants, which means that their goods consist mainly of foods and beverages. The volume is normally 60,000 order lines per day. The number of unique SKUs currently stored at the warehouse is 25,000, but customers can order from 50,000 different SKUs. They use a WMS supplied by an outside party.

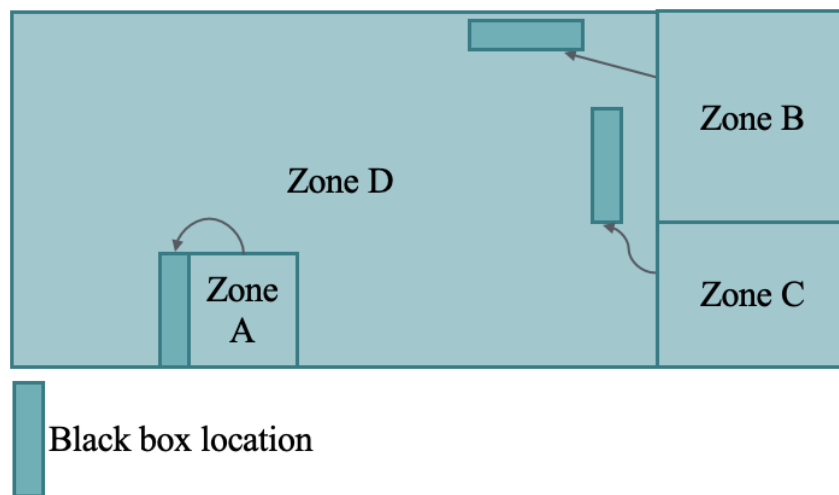
The warehouse of CC2 is divided into five zones, zone A, B, C, D, and E depending on the need for various storing conditions, in regard to both temperature and regulations. The primary picking occurs in four different zones where one is considered the main zone, zone D, and the flow in the last zone, zone E, is handled in parallel with the other zones from inbound to outbound. Since the flow in zone E is not included in the main picking, it will not be described further. The warehouse is handling products of smaller to medium sizes, where a substantial part of the SKUs are perishable goods.

The zones contain selective racking where the main picking is performed and zone D additionally contains smaller compartments. In all zones except for zone A, pickers are picking manually by forklift and they use pick-by-voice. The pickers pick from two levels, and the goods stored above those levels act as buffer storage. In zone A, the picking is performed on roll cages. The forklifts are pulling three roll cages, which are used for transportation of the goods from CC2, to their customers. The picking locations are mainly fixed, but some have dynamic locations. The locations are also adapted depending on seasonality. The pallets used as buffers have dynamic locations as close to the main picking of the goods as possible.

As mentioned above, the different zones exist because of different requirements for storage conditions. The picking in zone A, B and C occur partly in parallel but it is not of significance if the orders are being picked at the exact same time, or if they are picked at different times. When the goods have been picked in zone A, B and/or C, they are transported to new storage locations, in figure 5 called black box location, in the main picking zone, zone D. If the goods picked in a certain zone have too high a volume, they are not placed in a black box location in

zone D, but are taken directly to the outbound area. Some orders contain goods from all of the zones while some only contain goods from one, two or three zones. When the orders have been picked in zone A, B and C, they are released in zone D. The picked items in zone A, B and C are then passed on to the order pickers in zone D for completion of the order, according to a black box system. Figure 5 illustrates the flow from secondary picking zones to black box locations in the main zone.

Figure 5. *The flow from different picking zones in the warehouse to the main zone D.*



When black box picking was implemented at CC2, the main challenge was to adjust what volumes to include in the system. From the beginning the volumes were too large and the company has adjusted the volumes over the years for the system to work efficiently. Even though CC2 claims that the time consolidation took versus the time their current picking method takes is roughly the same, using black box picking has resulted in time savings further down the supply chain. An example of those time savings is that the roll cages do not need to be reorganized since black box picking ensures that the orders are kept together in the same roll cage.

CC2 argues that black box picking generally should be used in zones with lower volumes and smaller product sizes. The company states that the main picking zone is more efficient if the volumes from the secondary zones are small. However, using black box picking reduces the time needed for sortation. It is therefore important to find a balance between time saved during sortation and reduced picking efficiency in the main zone. The company previously used pick-

by-paper for order picking. However, to be able to implement black box picking, other support systems for the order pickers were required, as well as additional functionality in the WMS such as calculating that the order fits on the roll cage.

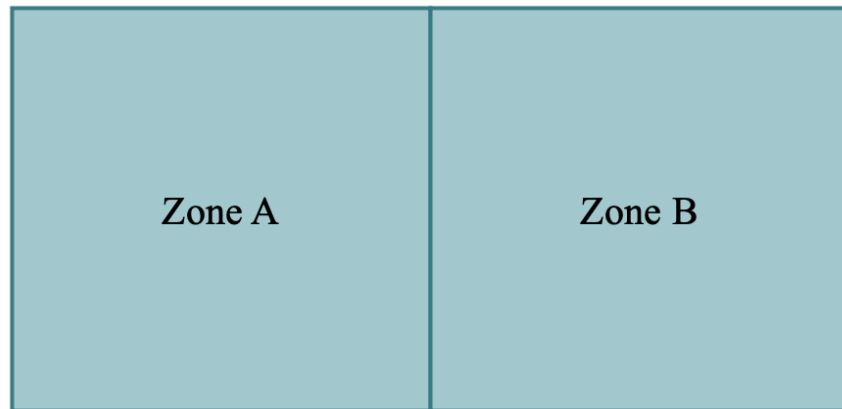
When interviewed, CC2 mentioned that the pickers were not satisfied with the picking process after the transition to black box picking. The main reason was the items picked in the black box location from zone B, which were fragile goods. Because of precedence constraints, the goods has to be picked last in the picking round, but since the items are stored in relatively large bins, it often leads to pickers having to repack the roll cages which leads to additional handling.

4.3. Case company 3

The third case company (hereby referred to as CC3) is a retailer of premium clothes and shoes. There are no dangerous goods and a limited amount of fragile goods at their warehouse. However, the products can be considered high-value goods. The company has an outbound order volume of 800-1000 orders, where the average number of order lines is 1.8. Between 30,000 and 35,000 SKUs are stored in the warehouse. CC3 uses an external WMS system which is connected to other systems used for the company's return flow and transportation handling.

CC3 uses two picking zones, zone A and zone B, visualized in figure 6, and the goods are either picked from one of those two zones, or from both of them. In the warehouse, a majority of the goods are stored in bin shelving where the compartment size varies, but hanging garment storage for garments is also used. Before the picking process is started, the orders are divided into bulk orders, containing only one piece per order, and multiple order lines. All of the order picking is performed manually using barcode scanners to confirm the pick. The bulk orders are all picked and placed into a big bin, while the orders with multiple order lines are placed in individual compartments onto a push cart.

Figure 6. *A visualization of CC3's picking zones.*



CC3 does not use pick-and-pass or black box picking currently, due to the fact that they do not have enough volumes to motivate the implementation of a pick-and-pass system. The company argued that pick-and-pass brings advantages to warehouse performance, but in their case, the advantages would be limited due to their low volumes and current sufficient order picking capacity. However, there are discussions regarding an implementation of an automatic storage system in the future, which would work as a complement to their manual order picking. A possible approach to combine the automatic and the manual order picking would be through a pick-and-pass system, or possibly a black box system. Unfinished orders picked in the automatic storage system would then be passed on to the manual order picking area for completion.

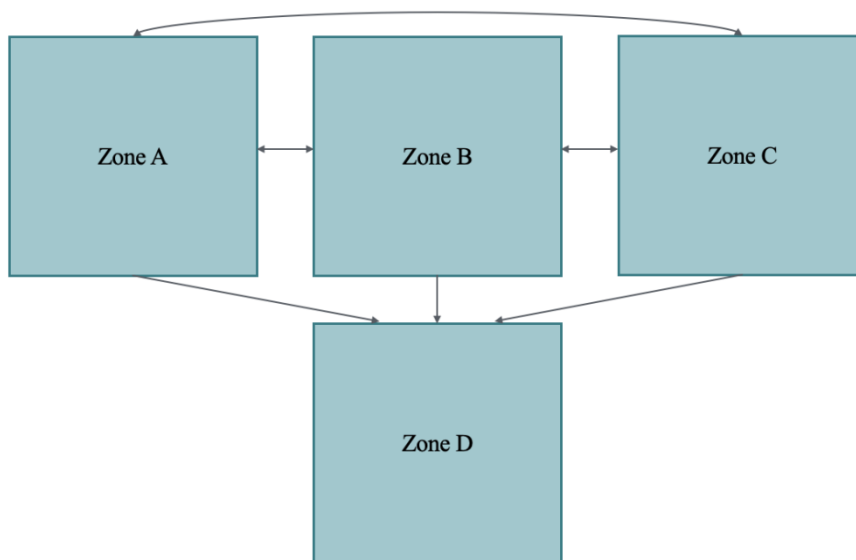
4.4. Case company 4

Case company 4 (hereby referred to as CC4) is a retailer of fashion and home goods with 11.5 million stored items. The company has an internally developed WMS. The warehouse of CC4 consists of three zones consisting of AS. Other goods are stored in additional zones containing for example fragile and dangerous goods. The picking in three zones is performed through an AS while the picking in the other zones is performed manually. Orders containing goods from multiple zones are first picked in the zones containing the least amount of goods, and then receive a new picking location in the zone containing the most amount of goods. Hence, there is no predefined order regarding which zones are picked first, but it is determined to reduce the amount of goods that have to be moved. CC4 could be considered to be using black box picking

as an order picking method since the goods are picked in one zone, and then moved to another where they are picked again. The described picking process of CC4 is visualized in figure 7.

The majority of the products in the warehouse are of smaller sizes which are handled by AS, but larger and odd-size products are handled in the warehouse as well. The products are generally not classified as fragile goods, but some of the products can be considered high-value goods.

Figure 7. *A visualization of CC4's picking zones.*



4.5. Interviews

In the interviews section, information from the interviews held with personnel working at Schenker, namely Tobias Karlsson (TK) working at Solution Design and Charlotta Larsjö (CL) working at Operational Excellence is presented. The interviews concerned pick-and-pass, however, the concept of black box picking was presented in the beginning of both interviews as the version of pick-and-pass in focus for the master's thesis. Thus, the data in the interviews section is presented for the pick-and-pass order picking method, and not only black box picking.

4.5.1. System

Regarding the WMS, TK says that the picking in the last zone must occur when the picking in the other zones is totally finished. When asked about important functions of a WMS, CL mentions volume calculation, verified drop of goods at black box location as well as, definition of different areas and picking zones. It is important to have a function for volume calculation since there is a need for knowing if the load carrier still has space for items, or not. The need for verification of drop at black box location is important since it is crucial to know when one process is finished, and when the next step can start. Definition of different areas and picking zones is needed since it is advantageous to know which goods are going to be pick-and-passed, as well as in which order they should be handled.

When asked if pick-and-pass works with all different types of identification systems, TK answers that there is a need for scanners since other methods would increase the risk of picking errors. The reason is that the items are picked two times, and therefore the risk of picking errors is increased. CL agrees that barcodes are important but does not see why picking using pick-by-paper wouldn't be possible. She explains that it is all a question of security and how many picking errors are allowed. CL also mentions that it is important to consider the labeling of boxes, and she does not think that it is enough to suppose that the items are in the right place after part of the order is completed, but that the items need to be registered in their new picking location.

Regarding transportation inside the warehouse, CL mentions that it is important to consider and define how often items should be moved from the different zones to the main picking zones. CL points out that an advantage of pick-and-pass is that different types of MHE can be combined in the same warehouse, forklifts and dollies are usually not combined for example.

TK concludes that a vertical storage lift is pretty optimal for pick-and-pass since one or two persons are working with it, and then, the items can be sent away. In an AS, it becomes important that the completed parcels are moved. It is also important that the route to the pick-and-pass area isn't too long. CL does not see that pick-and-pass is limited to certain storage systems.

Regarding the storage locations, CL explains that it is important to use locations of different sizes. The reason for different sizes of the storage locations is that the boxes in the black box location can be of different sizes. If all black box locations fit the largest boxes, it will require a large amount of space in the warehouse. It would therefore be beneficial to use black box locations that are adapted to the different sizes of the boxes instead. Previously in settings where both consolidation and smaller shelves have been used, the number of packages has been too large for the shelves, or in other words, the shelving space has not been sufficient for the packages.

Regarding the support systems for pickers, both TK and CL do not think that it matters which, or if they are used, for a pick-and-pass solution to work.

4.5.2. Product and order

According to TK, the characteristics of the product are important when designing a warehouse solution, since different product characteristics call for different warehouse solutions. CL agrees and mentions that pick-and-pass is only suitable for items that usually are consolidated, thus pick-and-pass is not suitable when items are sent as separate packages. Other product characteristics to take into consideration is if different dangerous goods types are mixed into the same package. However, the question of which goods are placed in the same parcels is not a question related to pick-and-pass. CL highlights the importance of placing odd-size items in the primary picking zone, and not in one of the pre-picking areas since it will make it easier to fit the goods.

TK mentions that the order characteristics affect the picking process in which way the orders are picked, namely if they are picked onto pallets or parcels. The most important aspect according to TK is if Schenker's customers require the items to be in the same parcel or not. If it is possible to send multiple parcels, there is no benefit in only sending one. For pick-and-pass to pay off, TK declares that there is a need for a critical mass. If, for example, ten orders are picked, but only one order goes to the area for pick-and-pass, there is a question of if the solution really is worth it.

Regarding the unit loads, TK says that it depends on how the picking solution is designed, but that it is important to avoid picking whole pallets from the black box locations when using pick-and-pass. He mentions that pick-and-pass would be inappropriate when picking full pallets in a single-level warehouse. CL said that the unit load does not matter as long as the items picked during pick-and-pass fit on the same unit load when the package is sent out.

4.5.3. Inventory

Regarding storage locations, CL mentions that it does not matter if the locations are fixed or dynamic.

4.5.4. Further characteristics of importance

Regarding challenges with parallel flows, TK mentions the case of short lead time. He does not think that an extra step would help in picking an order as fast as possible. CL also mentions lead times as a prerequisite when using pick-and-pass. It is important to consider if it is possible to pick an order in steps after each other since it will require a longer time period to pick something first, and then wait until the next item is picked. However, it also takes time to combine items in an area for consolidation. Even if there is a requirement for goods to be consolidated does not mean that pick-and-pass requires a higher amount of time than a solution using consolidation. Something to consider when performing pick-and-pass, according to TK, is the takt time, which is both complex and expensive.

TK brings up the importance of volume for a pick-and-pass solution to be worth it. A large customer (for Schenker) where the consumers' orders from a various assortment could be suitable for pick-and-pass, while smaller customers storing goods in a small area would not be worth it since there would have to be a lot of focus on balancing the zones. Factors which are good to have in place, but not necessary, for pick-and-pass to work is, according to TK, that pick-and-pass has to generate pay-back if there is not another value achieved by using the picking method.

TK mentions that when transitioning to pick-and-pass from an existing solution, it is important to take the human working with the processes into consideration. It is crucial that the picker

understands the reason behind the change. CL explains that pick-and-pass would be easier for the pickers than a consolidation solution since in a pick-and-pass solution, the combination of goods from different zones is only one order line. An advantage of pick-and-pass that TK sees is that the learning period for the picker could be shortened since the picker would only have to learn some tasks, and not all at once. The picking process could see increase in productivity as the pickers in certain zones becomes more familiar with how to pick certain articles, for example, picking smaller items on a cart, compared to picking 20 kg bags to pallets.

5. Analysis

This chapter provides an analysis of all factors identified in the theoretical framework. The analysis is supported by the empirical data collection including the four case companies and the two interviews at Schenker. Each factor is then classified as either a prerequisite, simplifying but not necessary, or not a prerequisite for black box picking. The results are summarized in table 4.

5.1. System

5.1.1. WMS

Both CC1 and CC2 have externally supplied WMS, while CC4 has an internally developed WMS using their own in-house developers. All of the WMS support the operations of black box picking in their respective warehouses. As explained by Rushton et al. (2021), a WMS can be adapted to fit a certain setting or provide specific functionality, which is the case for all companies concerning the black box picking functionality. CC1 and CC2 have not always used black box picking, instead, black box picking was implemented a few years after the warehouses opened. CC1 received the functionality after a request to their WMS provider, while CC2 already had the functionality in their WMS. Since CC4 has their own developed WMS, they can adapt the functions to ensure that it supports their processes. They can therefore optimize their WMS to their operations. It was stated by both CC1 and CC2 that the WMS is a requirement for black box picking to work. CL discusses several important functionalities which are required as support for pick-and-pass, including volume calculation, receipt of transport, and definition of picking zones. A WMS system with supporting functionality to

manage black box order picking is therefore considered to be of high importance for black box picking.

5.1.2. Identification system

An identification system is important for pick-and-pass to keep track of the items according to Ghiani et al. (2013). CC1 used barcodes as an identification system, it was not mentioned what type of identification system CC2 or CC4 used to keep track of their product during order picking. As discussed by Ghiani et al. (2013), the identification system is a critical factor for computerized warehouse management. The identification system should therefore be a critical factor for the warehouse management at CC1. As stated by CL, it is important to label boxes and register when the boxes arrive at the pick-and-pass location. The identification system could allow the order picker to register when products arrive at the black box location. The identification system is therefore considered to be of high importance.

5.1.3. Zoning

As explained by de Koster et al. (2007), pick-and-pass means that an order can be picked in multiple zones for completion. It is therefore impossible to use pick-and-pass, or black box picking, without more than one zone. CC4 has divided the warehouse into multiple zones based on the fact that the company has three ASs and a manual picking area. Both CC1 and CC2 have divided their warehouses into multiple zones based on product characteristics and building restrictions. When black box picking was implemented, the companies chose to use their already existing zones in the warehouse. Using already existing zones in a warehouse could possibly facilitate a black box implementation since it removes the need to create new zones. Creating new zones in the warehouse for black box picking could provide the benefit that the zones are specifically adjusted for a black box picking system. However, by using already existing zones it would be possible to remove one step in the implementation process and possibly facilitate the implementation. If CC4 implemented black box picking before or after their current warehouse layout was set was not mentioned during the warehouse visit. However, for CC1 and CC2 the zone layout was already set when they implemented black box picking. CC1 and CC2 therefore implemented black box picking because of the benefits the method could bring to their current zone layout in the warehouse, and not because of the method in

itself. Pre-existing zones are therefore considered a simplifying but not necessary prerequisite for black box picking.

5.1.4. Material handling equipment

For transportation and material handling, CC1 uses forklifts as well as forklifts connected to wagons, similar to tuggers and trains of tow carts explained by Baudin (2004). CC2 are using forklifts connected to roll cages, but not in all warehouse zones. CC4 mainly uses conveyor belts for the transportation of outbound parcels in the warehouse. For transportation between different zones, CC4 mainly uses push carts. Neither CC1, CC2 or CC4 mentioned that the choice of MHE had any impact on the black box system. Furthermore, instead of discussing what type of MHE is required for pick-and-pass, CL stated that an advantage of pick-and-pass is that it allows for a combination of different MHE's. The choice of a specific MHE is hence considered to not be a prerequisite for black box picking.

5.1.5. Storage systems

CC1 uses several different storage systems including selective racking in zone C, which, according to Kay (2012) can carry one to two pallets per spot and storing on a mezzanine in shelves in zone B. CC2 is also using selective racking in most zones and zone D also includes smaller compartments for storing. CC3 uses both bin shelving as well as hanging garment storage for garments. Lastly, CC4 mainly uses AS, which is an automatic storage (Rushton et al., 2021). CC1, CC2 and CC4 all use black box picking. Furthermore, CC3 had internal discussions regarding the implementation of an automatic storage system as a complement to the manual storage system. An order would then first be picked in the automatic storage and then be passed on to the manual storage for completion, according to pick-and-pass. From the empirical data from all four case companies, it seems that black box picking could work with several different storage systems. Furthermore, black box picking works with both manual and automatic storage systems, as shown in the examples with the case companies. In addition, CL stated that the storage system is not a limiting factor to if pick-and-pass is possible or not. Specific storage systems are therefore considered to not be a prerequisite for black box picking, since the method works with several different storage systems at the case companies' warehouses.

5.1.6. Support systems for order pickers

Both CC1 and CC2 are working with pick-by-voice as a support system for the order pickers. The order picker receives information in an earpiece on what to pick, and then confirms the pick through voice, as explained by Battini et al. (2015). CC2 mentioned that the order picking previously was conducted using pick-by-paper, which as described by Rushton et al. (2021) is that all information on what items to pick is put on a piece of paper. CC2 argued that a black box solution would not be possible with pick-by-paper. However, CC2's reasoning mainly focused on the lack of functions regarding volume calculations, thus not concerning the support systems for order pickers but WMS functionalities. According to CL and TK, what support system used for order pickers is not affecting pick-and-pass. However, TK stated that barcode scanners are beneficial for pick-and-pass to avoid picking errors. He explains it by saying that the risk of picking errors is increased when pick-by-paper is used, and therefore the risk further increases when an item is picked twice, as with black box picking. It is possible that the choice of support systems for order pickers has limited impact on the pick-and-pass, or black box picking usage as long as pick-by-paper is not used. Specific support systems for order pickers are therefore considered to be simplifying but not necessary for black box picking.

5.2. Product and order

5.2.1. Product characteristics

According to TK, product characteristics are an important factor to consider when designing any warehouse solution. CC1 provides medical equipment and consumable products, CC2 provides mainly food and beverages, while CC4 offers fashion and home goods. The majority of the products for all companies can be characterized as small to medium-sized products, where multiple products can fit on a single pallet. CC2 argued that black box picking generally is more beneficial for products of smaller sizes. That pick-and-pass can be more beneficial for products of smaller sizes is also stated by Dallari et al. (2009). Furthermore, CC1 has dangerous goods as well as refrigerated goods which are required to be stored in a certain zone in the warehouse. CC2 stores perishable goods that are required to be stored in refrigerated zones in the warehouse. According to Rushton et al. (2021), dangerous and perishable goods are

products that are characterized by certain risks in the logistics system and require certain adaptations. The adaptations include the need to keep dangerous goods in certain zones, and keep perishable goods at the correct temperature (Rushton et al., 2021). Both CC1 and CC2 store their products of higher risk in assigned zones in the warehouse, which are the same zones that are used for the black box picking system. The product characteristics therefore result in logical zone splitting in the warehouse which can be used for black box picking.

CC1 argues that when refrigerated goods are required to be picked as late as possible in the warehouse, black box picking is beneficial since the refrigerated goods can be picked at the end of the order picking route. However, having too large items to pick at the end of the order picking route might result in difficulties in stacking the items. The stacking problem is supported by Žulj et al. (2018) who discuss that limiting factors such as size can affect the possibility to stack items during order picking. It could therefore be difficult to pick too large items from the black box location at the end of the order picking route.

Product characteristics seem to have a substantial influence on pick-and-pass and black box picking. The product characteristics could act as a base when designing zones to use in black box picking due to storing requirements. Furthermore, the characteristics of the products could also affect the possibility to pick up items from the black box location. Product characteristics are therefore a prerequisite to consider when implementing black box picking.

5.2.2. Order characteristics

CL states that pick-and-pass generally is suitable for items that are otherwise sent to a consolidation area. TK argues that it is crucial if the customer of Schenker requires the order to be sent in the same parcel or not. The pick-and-pass method should therefore only be used for orders that are required to be sent in a single package. CC1, CC2 and CC4 manage a substantial amount of orders each day where some orders include black box picking, and others do not. CC3 however, has a substantially lower order volume per day than the other three and argues that their volume does not motivate a black box implementation. Black box picking could result in improvements for the company's order picking, which CC3 also recognizes, but they do not see a need to implement it at the moment. The decision is partly due to the fact that CC3 currently has sufficient capacity and efficiency in their order picking, which means that

there is no urgency in changing it. As mentioned by Onal et al. (2023) higher picking volumes lead to better pick lists, with a better possibility to batch orders together. It could therefore be the case that for a company handling large volumes, it is easier to use black box picking since the picking rounds would be improved. A prerequisite for pick-and-pass and black box picking could therefore be that the company should handle larger volumes at the warehouse.

Concerning order volumes in specific warehouse zones, CC2 argued that black box picking generally was more beneficial in zones with smaller volumes. CC2 has learned the optimal order volume from the secondary zones by trial and error. It is important to weigh the decrease in efficiency in the main picking zone that occurs with higher black box picking volumes against the additional handling later in the chain of operations. Therefore, depending on the order volume from different zones in the warehouse, black box picking could be more or less beneficial. For example, if a zone for dangerous goods has large order volumes, black box picking might not be the optimal solution. Due to the fact that black box picking possibly works better with large order volumes in the warehouse, and with smaller order volumes from specific zones, order characteristics are an important prerequisite to consider. However, it is important to take into consideration that for black box picking to work, the orders need to have more than one order line to ensure that they are picked in multiple zones.

As discussed by CC3, pick-and-pass can result in improvements even with lower order volumes. Related to the order volumes in the warehouse zones, TK states that it is important that a substantial amount of the orders batched together are sent to the black box location. If a substantial volume is not reached, pick-and-pass is not necessary. Thus, order similarity is of importance for black box picking to be advantageous. As explained above, order characteristics seem to have multiple implications for a black box system, and are therefore important to take into account. Although black box picking might work better with certain volumes in the warehouse or in specific warehouse zones, the method still seems beneficial in other settings as well, such as for CC3. Specific order characteristics are not required for a black-box solution to work, but certain characteristics, such as order similarity, could be simplifying but not necessary.

5.2.3. Unit loads

CC4 are mostly using tote bins as unit loads in the warehouse since tote bins are used in the AS where the majority of the company's products are stored. CC1 and CC2 on the other hand are primarily using pallets for storage in the main zones of their warehouses. The pallets are partially picked by moving the palletized goods to roll cages or roll wagons. For the black box locations, however, CC1 and CC2 use other unit loads. CC1 picks items from the secondary zones and places them in a sealed carton, before sending the order to the black box location in the main zone. CC2 mainly picks from the secondary zones into bins which are then placed in the black box location. Some items are placed directly into the black box location without being put into a unit load. Neither CC1 nor CC2 stores goods at the black box location using a pallet. Avoiding too large unit loads when picking in the secondary zones is also mentioned by TK, who states that pallets should not be used at the black box location. The reason could be that it is difficult to place one pallet onto another when picking. CL stated that as long as the item fits on the same unit load when the picking is done, all unit loads should work. I.e. if a whole pallet is picked, it is unnecessary to use a pick-and-pass solution since it is not possible to add more items to that unit load. CC2 mentioned that if the order picked in a secondary zone has too large a volume, it goes directly to the outbound area, without being placed in a black box location. The reasoning behind the goods not passing through the main zone is either that it will not fit in the designated storage locations, or that it will fill a roll cage itself making it unnecessary to include in the main zone. The company therefore seems to avoid storing orders of too large volume at the assigned locations for black box picking. Too large unit loads from the secondary zones to the black box location might therefore not be preferable when using black box picking. Using smaller unit loads is therefore considered to be simplifying but not necessary.

5.3. Inventory

5.3.1. Storage assignment

CC1 and CC2 are mainly using dedicated zones for the storing of products, with some dynamic locations as well. The black box locations however are placed in dedicated zones for both companies. CC4 is using dynamic slots for the products stored in AS, including the products that are picked in one zone and then placed in a new zone for continued picking. Less traffic

around the products could be an advantage with dedicated zones according to Baudin (2004), which might be beneficial around the black box locations and allow for easier retrieval of products picked through pick-and-pass. However, CC4 shows that black box picking is possible with dynamic slots as well, in their ASs. CL agrees that pick-and-pass should work both with fixed and dynamic storage locations. Black box picking therefore seems to work with different storage assignments. Storage assignments are hence considered to not be a prerequisite.

5.4. Framework result

The results from the analysis are visualized in table 4. The prerequisites are classified as high importance, simplifying but not necessary, and not of importance.

Table 4. *Identified prerequisites, simplifying but not necessary, and not prerequisites, for black box picking.*

Categories	Factors	Prerequisites	Simplifying but not necessary	Not prerequisites
System	WMS	<i>Black box picking functionality. E.g. volume calculation, receipt of transport, and definition of picking zones.</i>		
	Identification system	<i>Important to keep track of the item's location.</i>		
	Zoning		<i>Possible to use both pre-existing and new zones with black box picking, although pre-existing zones are simplifying.</i>	
	MHE			<i>Black box picking works with all types of MHE. A benefit of black box picking is</i>

				<i>that different types of MHE can be used.</i>
	Storage systems			<i>Black box picking works with all types of storage systems. Manual or automatic storage systems do not affect black box picking.</i>
	Support systems for order pickers		<i>Most support systems for order pickers can be used. Pick-by-paper is avoided to avoid picking errors.</i>	
Product and order	Product characteristics	<i>Smaller product sizes are preferable. Product characteristics result in logical zone splitting. Too large products at the black box location results in difficulties for the order pickers.</i>		
	Order characteristics		<i>Possibly preferable with larger order volumes. Smaller order volumes are preferable from specific warehouse zones. However, black box picking is applicable for most order characteristics as long as the order has more than one order line.</i>	
	Unit loads		<i>All unit loads should be possible to use with black box picking, but smaller unit loads from the secondary zones are preferable.</i>	
Inventory	Storage assignment			<i>Black box picking works with both fixed and dynamic storage assignments.</i>

6. Discussion

The following chapter concerns the master's thesis contribution, both in general and for the company of collaboration, namely Schenker. It also brings up sustainability aspects in relation to the findings of the report. Thereafter, a method discussion is conducted. Lastly, further research in the area of pick-and-pass and black box picking is discussed.

6.1. Contribution

The aim of this master's thesis was to identify the prerequisites needed for a black box picking system in a warehouse. Furthermore, the thesis would provide support for warehouse designers to facilitate the implementation of a black box system. By identifying, assessing, and grading prerequisites, the design process for warehouse designers has been facilitated through the creation of a framework that can be used as a first method for check-off. Accordingly, the aim of the master's thesis is fulfilled.

There are several important implications from the results of this master's thesis. The implications are both applicable for Schenker, but also for warehouses in general, to assess if black box picking is a viable solution. The framework can be used for new customers, but especially for already existing customer cases where many of the factors are already fixed. Warehouse designers can use the framework and the results from this master's thesis to evaluate if important prerequisites for black box picking are achieved. If a warehouse is lacking prerequisites, such as the correct functionality in their WMS, the warehouse designers probably should look at other alternatives than black box picking. However, if a warehouse is lacking factors that are simplifying but not necessary, such as a sufficient support system for order pickers, black box picking could still be beneficial but more evaluation might be needed. Since some factors of the framework are possible to change, warehouse designers could also use the framework to analyze which factors are in place, and which they could acquire.

For Schenker, the implications of this master's thesis will be that the department of Solution Design can use the framework when they are developing storage solutions for new customers. Another possible usage of the framework will be that the department of Operational Excellence can use it to develop already existing processes. The reason for Schenker wanting to investigate

black box picking was to be able to eliminate the consolidation processes currently used. The result of the master's thesis would most likely help Schenker with that goal since it simplifies the first decision process regarding black box picking. The master's thesis could therefore lead to black box picking being implemented and used by Schenker, leading to an elimination of consolidation processes. Since output was not a part of the study, it is impossible to conclude how the usage of a new picking method would impact factors such as picking quality and time savings for Schenker.

6.2. Sustainability

According to the triple bottom line, sustainability consists of social, environmental and economical aspects.

During this master's thesis, the focus area did not concern human aspects. However, it was clear that the usage of, and switch to, black box picking had implications for the pickers. CC2 mentioned that pickers had been complaining after the process changes because they needed to repack already filled roll cages. TK mentioned the importance of taking factors related to the working conditions for the pickers into consideration and explained the importance of pickers understanding the reasons behind changes. In the case of CC2, the social sustainability during the implementation of black box picking could maybe have been improved by further explaining why the picking method was changed. TK also explained that pick-and-pass would facilitate human characteristics since different people could pick things that they were better suited for than others. To conclude, black box picking can result in positive social aspects because of the reasons mentioned above.

CC2 explained that even though black box picking did not really change the warehouse's own efficiency, it led to more cages being assorted with goods going to the same places later in the supply chain. The already sorted roll cages lead to fewer resources needed later in the company's supply chain. The decreased need for repacking roll cages could have both social and economical implications since no worker had to repack heavy goods leading to both savings on the human body, and economical savings.

TK mentioned that the total cost of the orders is what matters, if there is no need for multiple items to be sent out as one package if there is no requirement from the customer. Regarding environmental sustainability, it is important to consider the environmental impact of sending one order in multiple packages. Even though the economic implications for Schenker would be the same regardless, the environmental impact of sending multiple packages should also be taken into consideration.

TK also mentioned that for pick-and-pass to be considered as an order picking method, it either has to be the most economical solution, or have another value achieved by using it. It is of course interesting to assess the economical sustainability, but it could also be of importance to evaluate which impact black box picking has on the other two sustainability factors.

6.3. Method discussion

All of the observations were performed over short time periods. To gain further insights, it could have been advantageous to perform observations over a longer time period. If the visits would have occurred during longer time periods, a greater understanding of the processes and insights about the human aspects of the pickers could have been collected. However, since the authors did not have access to the warehouses themselves and had to be guided by someone, longer observations were not possible. To further expand the data, it would have been advantageous if the authors would have performed more observations and interviews. Anyhow, the same problem as mentioned above was also applicable here, namely that the authors did not have access to the warehouses themselves. The warehouse visits occurred on the warehouse personnel's terms, and therefore it was not possible to perform more observations and interviews. The consequences of the smaller amount of warehouse visits could be different factors not being recognized.

As mentioned in the methods chapter, and more specifically in the subchapter about observations, the importance of taking field notes is highlighted by Hennink et al. (2011). As of now, only one of the authors took notes, and therefore, the recalling could possibly have been improved if both authors did. However, since only one author took notes, the other author was able to focus on the interview and could come up with relevant questions. Furthermore,

the interviews were discussed between the authors directly after they took place, to ensure that no important information was left out.

During the interviews, the interviewees mainly agreed with each other, with one exception. The reasoning behind the difference in answers could either be because the interviewees worked at different departments and therefore had different focuses, or because the questions were not asked in the exact same way during both of the interviews. The example of differences in opinions clearly shows the importance of considering which standpoint different actors have, as well as in which way questions were asked. Another reason behind the difference in answers could be that many questions concerned pick-and-pass in general, and not black box picking in particular. The broad definition could have resulted in the interviewees having different focuses when they answered. However, the definition of black box picking was presented before the interviews. Even if the answers concerned the general picking method of pick-and-pass, it should still be applicable for black box picking.

6.4. Further research

Further research in the area could include measurements in key performance indicators such as output (e.g. number of order lines per hour) and picking quality, as a consequence of a black box implementation. It would also be interesting to investigate process-related prerequisites for black box picking since the implementation of black box picking can require adaptations in the warehouse processes. By investigating the process-related factors it would be possible to achieve a broader understanding of successful black box picking solutions. The identified prerequisites from this master's thesis could be further investigated to more accurately point out specific subfactors and their specific impact. For example, a study could focus on the specific functions needed in a WMS to ensure that a black box solution works, or an analysis could assess the implications of using black box picking when combining automation and manual picking. Lastly, since black box picking is only one version of pick-and-pass, it would be interesting to study prerequisites for pick-and-pass to investigate if the master's thesis results are true for the whole pick-and-pass method.

7. Conclusion

The aim of the master's thesis was to identify the prerequisites needed for a black box picking system in a warehouse. Furthermore, the thesis aimed to provide support for warehouse designers to facilitate the implementation of a black box system. In order to fulfill the aim, a literature review was conducted, and several warehouses were visited where both interviews and observations took place.

In the literature review, several important areas in a warehouse were described which served as a basis for the construction of a framework to analyze necessary prerequisites for black box picking. The identified factors in the framework were classified as prerequisites, simplifying but not necessary, and not a prerequisite, based on the collected empirical data.

Warehouse designers can use the constructed framework to evaluate if the prerequisites needed for successful black box picking exist. For Schenker, the goal was to eliminate the consolidation process for certain customers. The framework can therefore be used by Schenker to assess if black box picking is a viable option in their order picking, in order to remove the need for consolidation.

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Appendix A - Interview questions Tobias Karlsson

1. Skulle du kunna beskriva hur processen går till när ni designar en lösning åt en ny kund?
2. Vilka är de viktigaste aspekterna att tänka på när ni skapar en kundspecifik lösning?
3. Hur påverkar produktens egenskaper vid design? (tex. Farligt gods och högvärdesgods)
4. Hur påverkar orderns egenskaper vid design? (tex. E-handel vs. butik, volymer, antal avgångar per vecka, vilket land ordern ska till osv)
5. Vilken vikt lägger ni vid vilka funktioner WMS-systemet stödjer när ni designar en lösning?
6. Vilka designaspekter tror du är viktiga att tänka på när man designar för stafettplock?
7. Vad tror du är viktigt att tänka på när man övergår till stafettplock för en befintlig lagerdesign?
8. Vilka förutsättningar ser du måste finnas för att man ska kunna använda sig av stafettplock? (ex. Zoner, WMS)
9. Vilka förutsättningar ser du som bra men inte nödvändiga för att stafettplock ska fungera? (ex. volymer)
10. Tror du att stafettplock funkar med alla typer av
 - a. Identifikationssystem? (tex. Scanner eller plock efter lista)
 - b. Hyllsystem
 - c. Stödsystem för plockaren (pick-by-voice, pick-by-light etc.)
 - d. Lastbärare (pall vs. kartong)
11. Ser du några lagerlösningar där stafettplock inte alls fungerar?

Appendix B - Interview questions Charlotta Larsjö

1. Vad tycker du är viktigt att tänka på när man designar ett lager/en lagerdel där pick-and-pass ska användas?
2. Hur påverkar produktens egenskaper en pick-and-pass-lösning?
3. Hur påverkar orderkaraktären en pick-and-pass-lösning?
4. Vilka funktioner behöver ett WMS-system ha?
5. Vilka förutsättningar ser du som viktiga när man implementerar pick-and-pass?
6. Finns det några förutsättningar som kan förenkla användandet av pick-and-pass men som inte är direkt nödvändiga?
7. Hur tror du att personalen i produktion påverkas av att använda pick-and-pass jämfört med något annat sätt att plocka på?
8. Tror du att pick-and-pass funkar med alla typer av?
 - a. Identifikationssystem
 - b. Hyllsystem
 - c. Stödsystem för plockaren
 - d. Lastbärare
 - e. Fasta och flytande lagerplatser
9. Ser du några tillfällen då det går att använda pick-and-pass men det är olämpligt?
10. Ser du några tillfällen då det inte passar att använda pick-and-pass?

Appendix C - Interview questions case companies

1. Kan du beskriva er nuvarande plockprocess?
2. Hur hanterar ni produkter i olika zoner? tex. lagring i AutoStore, oddsize och farligt gods (Outnorth bör ha alla tre)
3. Har ni någon sluttid som ni inte konsoliderar efter (Alt. någon sluttid där ni börjar plocka parallellt istället för pick-and-pass) eller skickas det godset dagen efter i sådana fall?
4. Vilka fördelar och nackdelar ser du med er nuvarande plockprocess?
5. (Inte om pick-and-pass används) Har ni funderat på att byta plockmetod? I sådana fall, till vilken?
6. Hur säkerställer ni orderhastighet och kvalitet?
7. Hur hanterar ni toppar och dalar vid exempelvis perioder med hög efterfrågan?
8. Vilket VMS-system använder ni?
 - a. (Om pick-and-pass används) Finns det funktioner i ert VMS-system som stödjer pick-and-pass eller har ni behövt utveckla det själva?
9. Vilka är era största utmaningar i er plockprocess?
10. Vilka KPI:s har ni och hur mäts dem?
11. Har du några tidigare erfarenheter från pick-and-pass eller andra plockmetoder utan konsolidering?

Frågor om pick-and-pass:

12. Har ni använt pick-and-pass sedan start?
 - a. Om nej:
 - b. Vilka var de största utmaningarna när ni började använda er av pick-and-pass?
 - i. Hur hanterade ni dem?
 - c. Hur ändrades produktionspersonalens roller efter övergången till pick-and-pass?
 - d. Hur påverkade pick-and-pass orderprecision och orderhastigheten?
 - e. Hur behövde ni anpassa ert WMS-system för att kunna använda pick-and-pass?
 - f. Kan du beskriva hur lagret behövde anpassas för att implementera pick-and-pass?

- g. Hur har pick-and-pass påverkat ert personalbehov och krav på personalen?
13. Vilka eventuella problem har ni observerat gällande längre ledtid vid pick-and-pass?
 14. Hur hanterar ni potentiella problem med spårning av ordrar och ansvar vid pick-and-pass?
 15. Hur har pick-and-pass påverkat ert lager?
 - a. Flöde?
 - b. Säkerhet?
 - c. Rutiner?
 16. Hur påverkar:
 - a. System? Dvs nuvarande layout, vilka resurser som finns, säkerhetskrav.
 - b. Human? Dvs fysiska och psykiska aspekter för de som plockar.
 - c. Product and order? Dvs typ av productt och typ av order som t ex mängd returer från kunder och krav på leveranstid.
 - d. Inventory? Dvs vilka produkter som finns i lagret samt var och hur de är lagrade.

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
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CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden
www.chalmers.se



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