Layout Redesign and Automation for a Lean Packing Process in a Distribution Center

Master Thesis for M.Sc. in Industrial Engineering and Management

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Preface

This thesis was conducted during the summer of 2019, as the final part of my engineering studies within industrial management and a master's degree within the field of supply chain management. The thesis was supervised by the Faculty of Engineering at Lund University in a collaboration with Alfa Laval.

I would like to express my gratitude towards the case company, and each of the members of the steering committee who have provided me their support during the course of the project. I would also like to thank the warehouse employees at Alfa Laval who allowed me to observe them in the process of data collection and provided their insights.

Finally, I would like to thank my supervisor at the Division of Engineering Logistics, Joakim Kembro, who has given me guidance and continuous feedback throughout the thesis.

Hanna Åberg
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Abstract

Background Warehouses serve an important role in many supply chains as they can affect business competitiveness in terms of both costs and customer service. However, the cost of operating a warehouse is often high due to the presence of many non-value adding activities. Lean is a philosophy that can be used to eliminate waste and enable cost reductions in companies. By implementing Lean warehousing and eliminating waste from warehouse activities, a firm's distribution capabilities can be significantly enhanced. Warehouse automation can cut waste and hence be used in Lean initiatives. By automating processes, several sources of waste that take place in a warehouse can be eliminated. One of the warehouse processes most likely to be highly automated in the next coming years includes the packing process.

Purpose The purpose of the master thesis is to identify waste and the corresponding root causes in the existing packing processes at AL DC Tumba and investigate how warehouse automation could be used for waste removal in developing a new packing area layout.

Research Questions The two following research questions are formulated:
RQ1: Where in the packing process does waste occur and what are the root causes?
RQ2: How can the packing process be redesigned for waste elimination by implementing warehouse automation and a new packing area layout?

Methodology To answer the research questions, a single-case study is performed. Primary data is gathered through observations and interviews. Two time studies are conducted to estimate the impact that waste has on the time of order packing. A proposed framework for Lean Warehousing is applied, using a combination of Lean tools such as the 5Ws, 5S and VSM. Secondary data is also collected from the case company's ERP system and the analysis of it builds an important foundation in proposing the design of a new layout.

Conclusions From observations, 40 wastes are identified and classified, of which 21 of them are directly or indirectly caused by the design of the packing area layout and therefore analyzed further. A layout that reduces or eliminates the 21 wastes is developed, and is estimated to reduce the packing process time by 42 percent, hence providing savings of 13,1 packing hours per day. The layout is based on a goods-to-man system that suggests dividing the packing process into three different flows and using a conveyor system to eliminate travel. Considering a growth of 20 percent, the dimensions of a new consolidation area are determined and the total number of packing stations is found to be six. The required lengths of the conveyors alongside each packing station are estimated. Recommendations for suitable locations for each section of the packing area are provided.

Keywords *Lean warehousing, Value stream mapping, Packing process, Packing area layout, Warehouse automation*

Sammanfattning

Bakgrund Lager utgör en viktig roll i många försörjningskedjor då de kan påverka ett företags konkurrenskraft genom inflytande på både kostnader och servicenivåer. Kostnaderna för lagerhållning kan emellertid vara väldigt höga till följd av kostsamma aktiviteter som inte skapar värde för kunden. Lean är en filosofi som tillämpas för att kunna minska företags kostnader genom att eliminera slöseri. Automatisering av lagerprocesser kan eliminera slöseri och användas som en del av en Lean filosofi. Genom att automatisera processer kan flera av grundorsakerna till slöseri elimineras. En av de lagerprocesser som är mest sannolik att automatiseras i framtiden är packningsprocessen.

Syfte Examensarbetet syftar till att identifiera slöseri och dess respektive grundorsaker i den nuvarande packningsprocessen på AL DC Tumba samt undersöka hur automatisering kan användas för att eliminera slöseri i en ny layout för packningsområdet.

Frågeställningar För att uppnå syftet har följande frågeställningar formulerats:
Frågeställning 1: Var i packningsprocessen förekommer slöseri och vad är grundorsakerna?
Frågeställning 2: Hur kan packningsprocessen designas för att eliminera slöseri genom automation och en ny layout för packningsområdet?

Metod Examensarbetet genomförs i form av en fallstudie, där packningsprocessen i AL DC Tumba studeras. För att besvara frågeställningarna används observationer, intervjuer och sekundärdata som datainsamlingsmetoder. Ett tidigare etablerat ramverk för Lean lagerhållning appliceras genom en kombination av olika Lean-verktyg så som 5Ws, 5S och 'Design av värdeflöden'. Analys av sekundärdata från fallföretagets ERP system skapar en förutsättning för att ta fram förslaget på en ny layout för packningsområdet. Slutligen görs en lönsamhetsbedömning av de föreslagna förändringarna, genom att använda resultatet från två genomförda tidsstudier.

Slutsatser Genom observationer har 40 olika källor till slöseri identifierats i packningsprocessen, varav 21 av dem beror av packningsområdets layout och därför vidare analyserade. En ny layout som eliminerar slöseri har tagits fram. Genom implementering av förslaget minskar tiden för packningsprocessen med 42 procent, vilket sparar in 13,1 packtimmar per dag. Layouten utgår från ett gods-till-man system där ett conveyor system används för att minska transporter. Packningsområdet designas för att kunna hantera en tillväxt på 20 procent. I den nya layouten delas godset upp i tre olika flöden. Konsolideringsområdet utgörs av ställage med kortare djup än i dagsläget. Antalet packstationer för att mäta kapacitetskaven beräknas till sex, där varje packstation har ett tillhörande rullband. Förslag på placering av samtliga sektioner i packningsområdet ges.

Nyckelord *Lean lagerhållning, design av värdeflöden, packningsprocess, layout för packningsområde, automatisering av lagerhantering*

Abbreviations

AL – Alfa Laval
A/SS – Accumulation/Sorting System
BG – Bulky Goods
DG – Dangerous Goods
DC – Distribution Center
ERP – Enterprise Resource Planning
FOM – Frequency of Movement
KPI – Key Performance Indicator
LCT – Logistics Control Tower
MHE – Materials Handling Equipment
OFS – Order Fulfillment System
PRP – Problem Resolution Process
RFID – Radio-Frequency Identification Technology
RQ1 – Research Question 1
RQ2 – Research Question 2
SKU – Stock Keeping Unit
SOP – Standard Operating Procedure
TPS – Toyota Production System
UoA – Unit of Analysis
VSM – Value Stream Mapping
WCS – Warehouse Control System
WMS – Warehouse Management System

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Chapter 1

Introduction

The introduction includes a theoretical background on the research topic, a description of the problem that the case company is experiencing and the purpose together with the research questions of the thesis. The delimitations and outline of the report are also presented.

1.1 Background

From having been considered as an expense burden, warehouses are increasingly being regarded as a strategic component of modern supply chains (Kembro et al., 2018). For most supply chains, warehouses are important components as they represent a significant share of logistics costs and are critical to achieving high service levels to customers (Baker & Halim, 2007).

The different warehouse processes consist of receiving, put-away, picking, packing and shipping (Bartholdi & Hackman, 2014). Order picking is the most labor-intensive warehouse process and is estimated to account for 50-65% of warehouse operating costs (Bartholdi & Hackman, 2014; Jiang et al., 2018). Thus, order picking has been the main focus of previous warehousing research (Jiang et al., 2018). Packing can also be labor-intensive as each item of the customer order must be handled individually, but in general requires less traveling than the picking process (Bartholdi & Hackman, 2014).

Bartholdi & Hackman (2014) differentiate between different types of warehouses, primarily defined by the customers that they serve. Amongst the different categories of warehouses, there are several types of DCs, typically distributing either products to retail stores, e-commerce business or spare parts. Distribution warehouses are often characterized by the storage of a large product range, whereas the quantities per customer order may be small, thus increasing the time of the OFS (picking, sorting, packing) (Rouwenhorst et al., 2000; Russell & Meller, 2003). In distribution logistics, companies need to accept late orders while still providing timely delivery between very tight time windows, shortening the time available to pick and prepare the order for shipment (de Koster et al., 2007).

Cagliano et al. (2018) describe warehouses as the nodes that link the upstream and downstream supply chain, thus affecting the business competitiveness in terms of both costs and customer service. However, costs can be remarkably high due to the presence of many non-value-adding activities. The increasing need and requisite to improve supply chain performance is forcing warehouses to cut waste by eliminating non-value adding activities (Abushaikha, 2018). Lean production, originating from TPS, is the most widely known approach for industrial improvement (Dotoli et al., 2015). Initially, the goal of the Lean philosophy was to eliminate waste and enable cost reductions by creating streamlined systems at a manufacturing level (Shah, 2016; Dotoli et al., 2015). Waste can be defined as *"anything other than the minimum activities and materials necessary to perform a particular process"* (Abushaikha, 2018). As organizations experienced the benefits of Lean and the importance of adopting its principles throughout the enterprise to remain competitive, other principles started to borrow Lean principles from the manufacturing literature (Sharma & Shah, 2016; Abushaikha, 2018). Logistics and supply chain has been a proven area in which waste reduction practices can be successfully implemented (Abushaikha, 2018). In this context, Lean warehousing could play a significant role in achieving lower logistics costs and efficiency in a pull supply chain driven by customer demand (Cagliano et al., 2018). However, warehouse operations from a Lean perspective have been given less attention compared to other logistics functions (Abushaikha, 2018). Within the research community, Lean principles are only recently starting to be applied to warehouses (Dotololi et al., 2015). According to Abushaikha (2018), recent research shows that there is a positive relationship between reduced levels of warehouse waste, warehouse operational performance and distribution performance. By eliminating waste from warehouse activities, a firm's distribution capabilities can be significantly enhanced. Thus, this indicates opportunities to minimize the non-value adding activities through the identification of waste activities.

Warehouse optimization depends upon opportunities to reduce or eliminate warehouse waste (Sun et al., 2018). Automation can cut waste and be used in Lean initiatives (McGuire, 2016). By eliminating manual processes and use automated picking and sorting systems, MHE as well as automatic identification technology (e.g. barcodes, RFID and voice technologies), warehouse automation can help warehouse workers when searching for order items, picking and sorting the orders and transporting them through the warehouse (McGuire, 2016; Sun et al., 2018). Another advantage of automation is its ability to reduce human errors (McKinsey, 2017), which is considered wasteful (Jones, 1995). Along with increased volumes, enterprises have to consider improving its operations through automation (Sun et al., 2018). One of the areas where automation is of paramount interest is the packing process (Dubey & Dai, 2006; Kembro & Norrman, 2019).

According to Specter (2015), the packing station design is an aspect of the OFS that historically has not been given a lot of considerations. However, DCs are increasingly re-evaluating the importance of their packing areas. Companies are realizing that poor packing station design will turn the packing process into a bottleneck and that the workstations must be properly integrated into the warehouse facility and its flows. The placement of each piece of packing support equipment, including scanner, keyboard, printer, tape, and label stock, must be considered to increase space efficiency and worker productivity. As companies are aiming to maximize throughput, the packing stations have evolved. For example, mobility is added to the packing station, fully automated packing systems are being implemented, and new configurations for improved ergonomics are enforced.

1.2 Problem Formulation

Today, AL DC Tumba is facing the challenge to handle a high throughput of emergency orders for spare parts as the time products spend in the OFS is considerably long. As a large share of orders is considered as emergency orders that are released for order picking close to the final shipping deadline at 5 p.m., it becomes difficult for the packing team to pack all orders in time for dispatch. This causes stress for the DC's employees who are working within the packing team, which can result in an increased risk of human errors, reflecting in an increased risk of customer delays and claims. As a result of the current design of the OFS, it sometimes takes hours from order release until an order is completed and ready for dispatch.

The current layout of the packing area was set approximately ten years ago. Since then, no major changes have been made. Meanwhile, the volumes that are being handled in the warehouse have increased by about 20-30%. Since the current packing area is not designed with the ability to handle such high volumes efficiently, the packing process turns into a bottleneck in the OFS. With an economy that is currently booming, this could result in even higher volumes in the future. This would inevitably lead to even more inefficiencies. Order packing is one of the crucial processes within DC Tumba that has been overlooked in the past, therefore requiring to be improved.

AL's customers are distributed across the globe and demand fast and timely deliveries of spare parts from the DC. This puts a requirement on AL to have the ability to accept late orders while still providing high customer service levels and deliver the correct products, in the correct quantity, on time. Thus, AL needs to identify which activities in the packing process that can be improved by the elimination of waste to create a more lean outbound flow and to be able to handle even larger volumes in the future. As waste seems to be built in the current packing process, AL DC Tumba is considering a redesign, and a shift to a packing process where each order is received for packing through a goods-to-man system. The design of a new packing process will inevitably require a new packing area layout to be implemented.

1.3 Purpose and Research Questions

The purpose of the master thesis is to identify waste and the corresponding root causes in the existing packing processes at AL DC Tumba and investigate how warehouse automation could be used for waste removal in developing a new packing area layout.

To address the purpose, the following research questions will be answered:
RQ1: Where in the packing process does waste occur and what are the root causes?
RQ2: How can the packing process be redesigned for waste elimination by implementing warehouse automation and a new packing area layout?

1.4 Description of the Case Company

AL is a Swedish company that specializes in the production of products and solutions for heavy industry. Their products are used to heat, cool, separate and transport products such as oil, water, chemicals, beverages, food and pharmaceuticals. AL currently has six distribution centers worldwide for the distribution of spare parts. The DC in Tumba stores 14.000 stocked items (SI), and another 68.000 non-stocked (NS) items that are ordered and then stored to customer order for consolidation with other SI, as drop-shipments are generally not carried out. Since the product portfolio is so large, this adds complexity to the warehouse operations. The DC does not experience any seasonalities with regards to volume, except for a small drop in demand during the summer months.

Historically, DC Tumba has been performing well. Last year, the warehouse completed and shipped 710.000 order lines, making it the largest DC at AL. During 2018 the DC received 246 claims, translating into a claim rate as low as 0,06%. The packing team is currently above 99,5% for the KPI “Deliveries On Time”. The focus has been put on creating Lean processes and eliminating waste, where the Lean Six Sigma DMAIC methodology has been an important roadmap for continuous improvements. VSM is a tool that has been used to eliminate waste, but so far this has only been performed for the warehouse processes at a high level, from door to door within the warehouse, and not at a lower level by looking at the activities which constitute each warehouse process: receiving, put-away, order picking, packing and shipping.

1.5 Focus and Delimitations

The warehouse processes at the DC can be divided into two different flows: the Make Order (MO) flow and the Customer Order (CO) flow. The MO flow includes kitting of items into service kits, before such kits are packed in a customer order in the CO flow. Items that are not included in any service kit will only pass the CO flow, whereas service kit items will pass both of the flows. The goods can also be classified depending on the weight of it. Goods weighing under 22,5 kilos are classified by AL as “light goods”, whereas everything above that is classified as being heavy goods.

The scope of the thesis is illustrated in Figure 1. The thesis is delimited to the packing process for the CO light goods flow, neglecting the MO flow and the CO heavy goods flow entirely. The main focus will be on the packing process but as the packing process is highly affected by the performance in the picking process, and especially the sorting process of the CO light goods in the interface between the picking and packing process, these are also considered to some extent. The heavy packing area at the DC is out of scope. The same applies for the order deadlines which cannot be changed due to customer/LCT needs. The WMS module in the company’s ERP system, Movex, will not be considered as a factor to analyze as it cannot be changed since the software is used throughout the company.

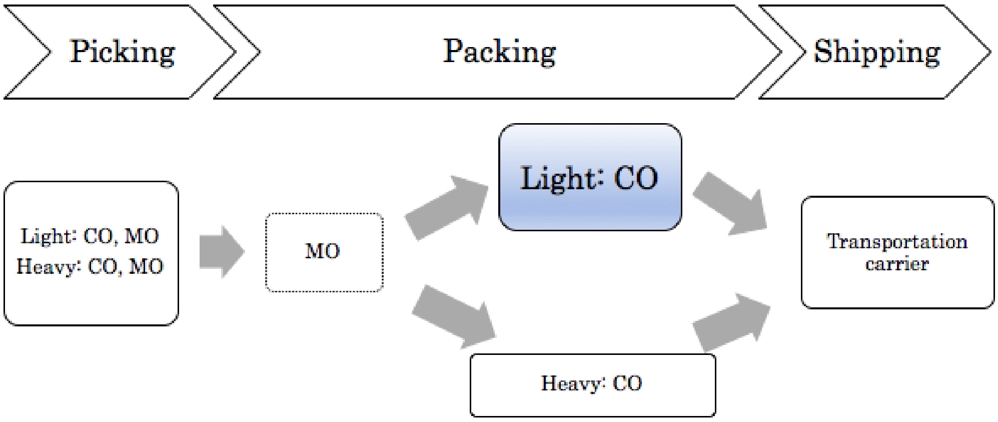

Figure 1: Illustration of the scope of the thesis

1.6 Report Outline

The outline of the report aims to clarify what each chapter includes.

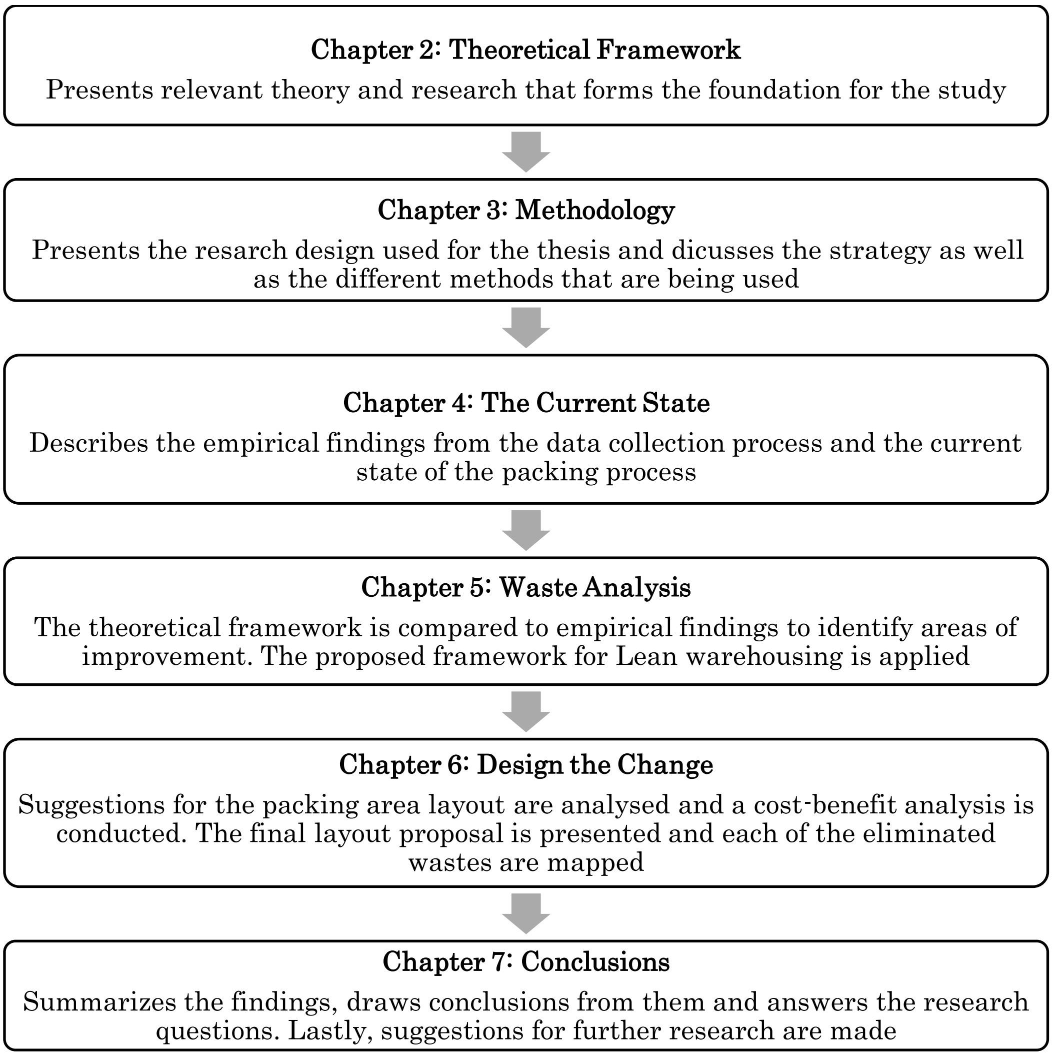

Figure 2: Outline of the report

Chapter 2

Theoretical Framework

The following chapter summarizes relevant theories and research related to the two research questions. Literature in the field of warehousing, warehouse design and design aspects for packing stations is presented. To address RQ1, literature on Lean warehousing is presented. To address RQ2, literature related to Lean warehousing and its synergies with warehouse automation is outlined. A summary of some of the available automation solutions that are applicable for packaging as well as sorting is provided.

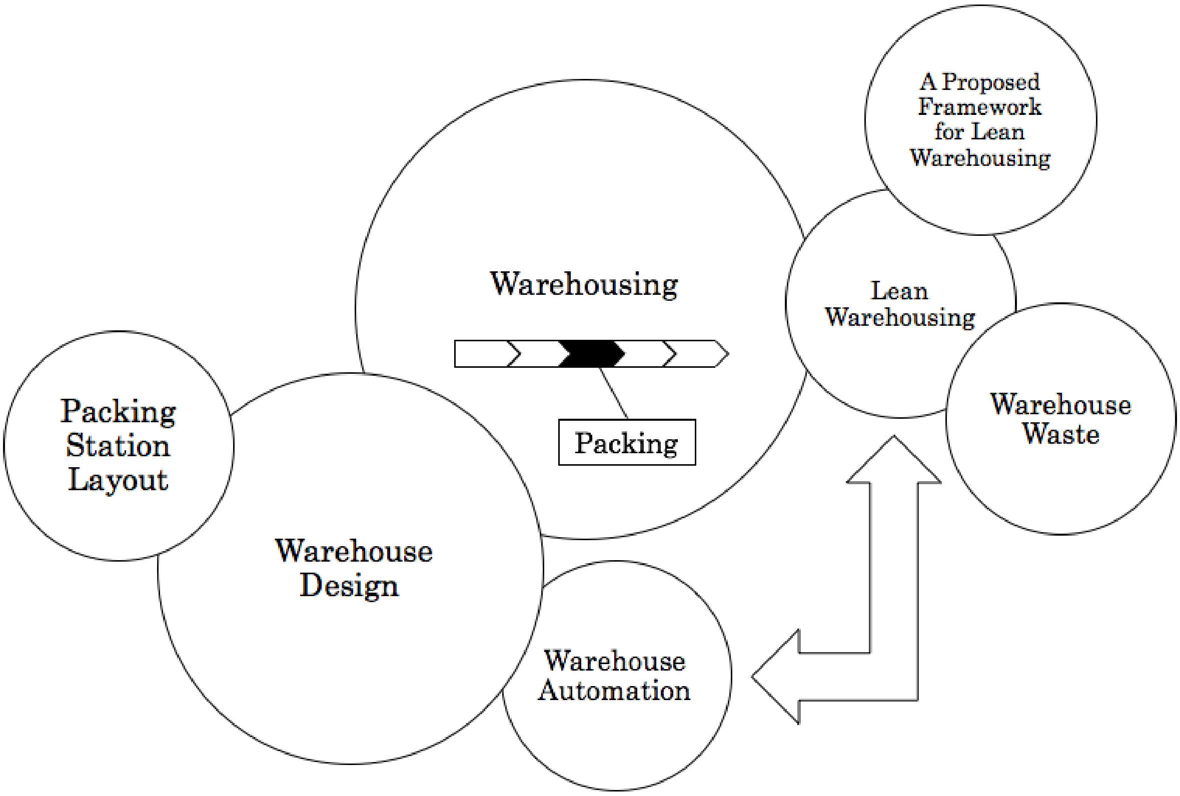

Figure 3: Theoretical Framework

Figure 3 shows the interconnections between the different areas of the Theoretical Framework that is to be presented in the chapter.

2.1 Warehousing

2.1.1 Warehouse Processes

Warehouse operations take place through five processes: receiving, put-away, order picking, packing and shipping (Bartholdi & Hackman, 2014). These are further described in Table 1.

Table 1: Description of the five warehouse processes (de Koster et al., 2007; Abushaikha, 2018; Bartholdi & Hackman, 2014)

Receiving	Includes the unloading and inspection of goods to ensure they are of the correct quality and quantity
Put-away	Involves the transfer of the received goods from the receiving area to its designated storage locations
Order picking	Involves picking of a customer order that has been placed. Sortation of customer orders is required if the orders have been picked in batches, where orders are picked in parallel by multiple pickers
Packing	After picking and sortation, the orders have to be packed and made ready for delivery to the customer
Shipping	After the order has been packed in the appropriate containers, it is loaded on freight carriers for transportation to the customer

2.1.1.1 Inbound Processes

According to Bartholdi & Hackman (2014), products typically arrive to the warehouse in larger units such as pallets, resulting in low labor requirements. Hence, in a typical DC the receiving process represents about 10 percent of the total operating cost. Put-away requires a fair amount of labor as products sometimes need to be moved to storage locations that can be located considerably far away from the inbound area. The put-away process typically represents about 15 percent of total operating expenses in a warehouse.

2.1.1.2 Outbound Processes

As confirmed by Bartholdi & Hackman (2014), order-picking is the most labor demanding process, representing about 55 percent of total operating costs. This is mainly due to the high portion of labor that is required when traveling to every storage location to collect each item belonging to a customer order. When designing the picking process, most efforts are directed at reducing the unproductive time for traveling. Sortation is required in between picking and packing if the customer orders have been picked in batches. This is further elaborated on in section 2.1.2.3.

Packing requires less traveling compared to picking, but is also considered as labor-intensive in some warehouses, as each piece within a customer order needs to be handled individually. As customers require their order items to be shipped in as few containers as possible to reduce shipping charges, this complicates the packing process since it implies that all parts of an order must arrive for packing together. Otherwise, items have to wait for consolidation before packing. Moreover, checking if a customer order is complete and that the correct products and amounts are being sent to the customer is an additional step that is often carried out as the order is being packed. In an article by Inventory Operations Consulting LCC (2019), it is stated that although order packing and shipping have not been given as much attention in research as order picking has, they still constitute two critical processes for any distribution center. Being able to use resources efficiently and meet quality and throughput requirements requires adequate planning of checking and packing methods, packing station layout and takeaway lines or lanes.

In line with Bartholdi & Hackman (2014), the shipping function generally handles larger units than picking and packing, as packing has consolidated several items into fewer containers. As a consequence, the labor requirements will be lower. Freight is sometimes staged before shipping, which creates more work because the freight must then be double-handled.

2.1.2 Warehouse Design

It is in Baker & Canessa (2009) opinion that with the critical impact that warehouses have on customer service levels and logistics costs, it is imperative to the success of a business that warehouses are designed to function cost-effectively. This is especially important as the costs of operating a warehouse are largely determined already in the design phase. As believed by Abushaikh (2018), firms can improve their distribution performance through the optimization of warehouse design and operations. By achieving internal efficiencies in the distribution function and streamlining the different warehouse processes, improvements in the performance in the customer-facing operations can be achieved.

In line with Kembro et al. (2018), there are numerous factors to consider when designing efficient and effective warehouse operations, including the physical layout, storage and handling equipment, automation solutions, information systems and labor management. Balancing the different design components is not a simple task as many of them are interrelated. Focusing on separate parts only could lead to a misfit between the different warehouse processes, resulting in sub-optimization. A general guideline for warehouse design is to create a layout that results in smooth product flow, avoids double handling and resolves bottlenecks (Bartholdi & Hackman, 2014).

2.1.2.1 Design Aspects and Resources

Figure 4 provides an overview of different factors influencing the warehouse design as well as various aspects and resources that must be acknowledged. In accordance with Kembro & Norrman (2019), one decision variable in the design phase regards the level of automation. The physical layout, including the number of aisles, depth of lanes and height, needs to be determined. Rouwenhorst et al. (1999) distinguish a number of resources, similar to the ones identified by Kembro & Norrman (2019). For storage, warehouse equipment such as different storage units and storage systems, ranging from simple shelves to highly automated systems, are fundamental. For put-away and picking, equipment such as trucks, trolleys and barcode scanners will be needed. After picking, MHE for the preparation of customer orders is also required. Such equipment includes sorter systems, palletizers and truck loaders. One essential information system for a warehouse is the WMS. Personnel also constitutes an important resource, and issues related to ergonomics, scheduling, rotation of tasks and the number of shifts need to be considered.

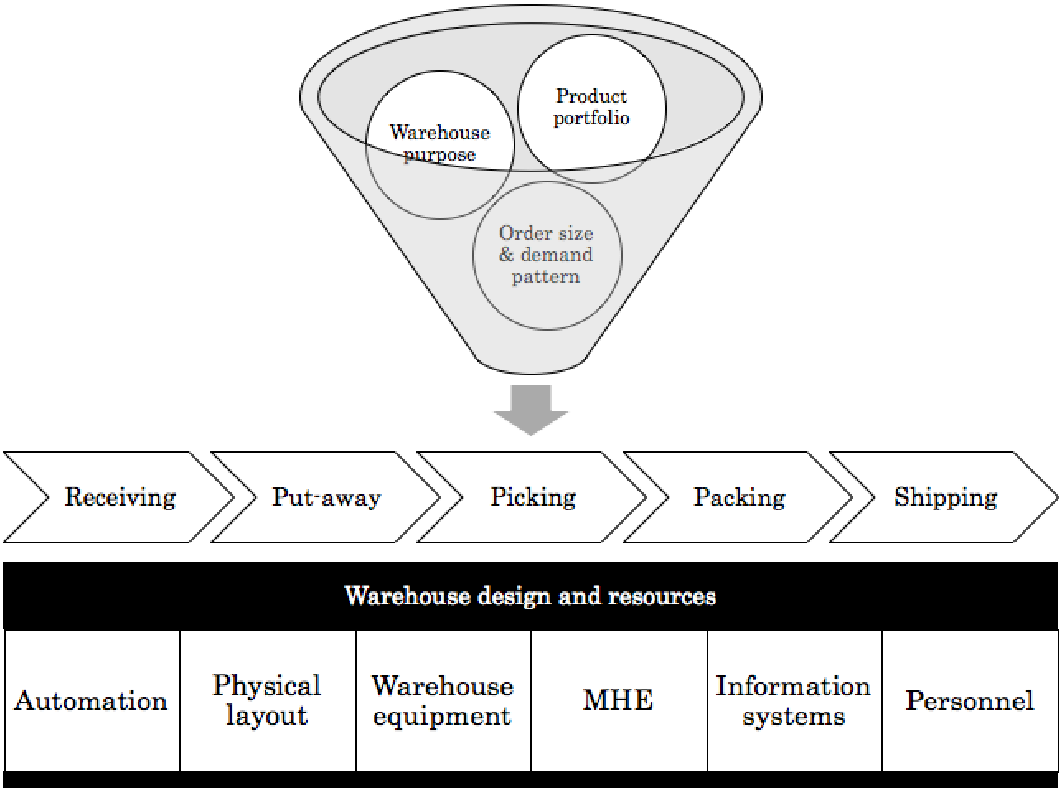

Figure 4: Overview of the main warehouse processes, design aspects and resources (Adapted from Kembro & Norrman, 2019)

2.1.2.2 Strategic, Tactical & Operational Design Decisions

Rouwenhorst et al. (1999) consider three different levels of warehouse design problems. On the strategic level, decisions that have a long term impact and most often concerns high investments are considered. These decisions mainly address the design of process flow and selection of warehousing system. Decisions on a strategic level include the type of storage systems and storage units, picking strategy and type of sorting system. On a tactical level, the layout of the overall system and the dimensions of its different areas are established. The number of MHE and personnel are examples of tactical decisions. Finally, at the operational level, processes have to be carried out within the constraints that are set by the strategic and tactical decisions that have been made. The design problems at the strategic and tactical levels often interfere with each other, but at the operational level policies have less interaction and can therefore be analyzed independently from each other.

2.1.2.3 Single, Order Batching and Zone Picking

According to Bartholdi & Hackman (2014), order batching and zoning are two topics that will be addressed when designing the picking process. A general decision in a manual warehouse is whether an order should be picked by a single or by multiple pickers at a time. The common picking methods include single, batch, zone and wave picking. To improve the efficiency of the order picking processes by reducing the unproductive travel time, order batching, a picking strategy where a set of orders are grouped into batches and then picked, can be applied (Jiang et al., 2018; Boysen et al., 2018a).

Koster et al. (2007) describe another alternative to parallelizing the picking process, zone picking, where the order picking area is divided into zones. Each order picker will then pick the part of an order that is stored in the zone that has been assigned to the picker. Both zoning and batching policies intend to reduce travel distances and shorten the time to pick an order but will also complicate the sorting process as it requires the coordination and consolidation of multiple work (Bartholdi & Hackman, 2014). As believed by de Koster et al. (2007), the main disadvantage of both policies is that they require a subsequent order consolidation before shipment to the customer. Two approaches can be used for the sortation and consolidation of an order when the zoning policy is applied: progressive assembly, where an order will be picked and passed through all relevant zones, and synchronized, where order pickers start on the same order in its designated zone and then merge the partial orders after picking. A key metric to measure the impact the strategy has on the performance is the flow time, which is the time from the order arrival into the system until the order is ready for shipment (Bartholdi & Hackman, 2014). Jiang et al. (2018) state that using a pick-and-sort strategy comes with a high possibility of either blockage in the buffer area or having no orders in the buffer. This will result in either the stagnation of the picking process or idleness in the sorting-packing process. To minimize the total time of picking, sorting and packing for a set of orders, the sequence of batches should be considered.

Kembro & Norrman (2019) address a second form of order batching. As opposed to postponing the sortation process, the second type of order batching policy implies that orders are being picked and sorted according to customer order simultaneously when picking. This entails that the picker will pick and sort each article in different storage bins at the same time, where each storage bin contains a single customer order. The advantage of this is that items are directly sorted according to customer order, eliminating a subsequent sortation process. The disadvantages are that it adds time to the picking process, and since the customer orders are often picked to storage bins and not the final shipping container, an additional activity is required when each customer order is packed and prepared for dispatch, resulting in double handling. If zoning is applied, but each article is still sorted in storage bins by customer order within each zone during picking, multiple sortation points are also resulting in double handling.

2.1.2.4 Designing for Fast Throughput

Kembro & Norrman (2019) discuss how several contextual factors that influence commerce businesses will impact the warehouse configuration. One of the configuration aspects is speed, characterized by short lead time requirements, geographical dispersion and differentiated goods. A large proportion of warehouses offers same-day deliveries and hence need to focus on the reliability of speed and accuracy (Baker & Canessa, 2009). Emergency orders of spare parts are generally urgent, as expensive capital equipment is likely waiting for repair (Bartholdi & Hackman, 2014). According to Kembro & Norrman (2019), companies with a focus on fast throughput should aim to create a warehouse design that enables fast flows and shortens internal lead times to the extent that is possible. In general, double handling should be avoided and activities such as sorting should be performed in as few steps as possible. For example, sorting by customer order when picking, and then later when packing the order and also before shipping will result in unnecessary and additional time-consuming work. To reduce the total lead time for a customer order, the sortation process should be delayed and should not be carried out in more than two steps. Another way to reduce internal lead time is by eliminating potential bottlenecks in the material flow. Some companies are moving from batch picking to a trolley or pallet towards picking directly into the shipping carton. The double handling when sorting and packing an order can be avoided by the use of two different strategies. During batch picking, the items can be sorted directly by customer order into the shipping carton, labeled and ready for dispatch. Another solution is to postpone the sortation and packing process by the use of automation solutions such as conveyors.

2.1.3 Design of Packing Station Layout

According to Specter (2015), the design aspects of packing stations are given more attention as DCs are re-evaluating the importance of their packaging areas. DCs are no longer just setting up a few tables for packing between the picking and shipping zone, but will rather examine the entire flow at a more detailed level. The workstations need to be properly integrated into the warehouse facility and its flows as poor packing station design will most likely turn into a bottleneck in the outbound flows.

Figure 5: Packing station (Specter, 2015)

A proper design of the packing stations in a DC requires a good understanding of how things move in and out of the packing area, as well as of the process of movements required to fulfill an order. The placement of every single piece of packing support equipment, such as scanner, keyboard, printer, tape, label stock and more, must be considered carefully. This is not only to increase the accessibility of them, but also to eliminate wasted space.

2.1.3.1 Ways in Which Packing Stations Have Evolved

As the emphasis on maximizing throughput has increased, packing stations have evolved. Specter (2015) suggests some of the new productivity-boosting features and configurations, including customizable features for improved ergonomics, mobile packing stations and fully automated packing stations. The first two will be further explained in the following sections. The latter will be addressed in section 2.4.3, as warehouse automation will be further discussed.

2.1.3.1.1 Customizable Features for Improved Ergonomics

There needs to be a balance between efficiency and ergonomics, particularly as a physically comfortable worker will also be a more productive one. Forward-thinking companies are looking to not only eliminate stressful and repetitive motion injuries amongst their staff, but also for ways to increase productivity and efficiency through a packing station design that requires less movement within each work cell. Such companies also recognize that all jobs are not the same, and that work stations need to be designed differently depending on the products they are designated to pack. This requires packing station configurations that match different functions within the same warehouse facility.

To accommodate operators of different heights, packing stations should include electric-powered height adjustments. This feature will allow operators to effortlessly adjust the height of the station so that all necessary items, such as barcode scanner, keyboard, boxes, labels and tape, are more easily reached regardless of the operators' stature. The packing station should also be configured to eliminate walking. Combining a shorter table for packaging with a sliding shelf underneath it can eliminate the need to walk within the work cell to reach items. This saves the number of steps each operator takes per package, ultimately saving time.

2.1.3.1.2 Mobile Packing Stations

Whereas one way to cut time for the order packing process is to automate it, another alternative is to add mobility to a packing station. Mobile pick/pack carts that can ride on wheels and have battery-powered wireless computing, scanning, printing and picking modules can be used for the fastest-moving SKUs. Instead of picking to storage bins, the cart is pre-staged with shipping cartons, enabling the items to be picked directly into the shipping carton. This aligns with the strategy of design for fast throughput, previously discussed in section 2.1.2.4, as double handling is eliminated. The printer generates the shipping label, which is affixed to the order's shipping carton by the picker. When all picks have been completed, the cart is handed over from the picker. The boxes are sealed and routed to the designated transportation carrier. Within the same area, additional pick/pack carts can be staged, allowing the picker to take the next cart and then repeat the process. The use of such mobile pack stations allows for picking and packing on the go, thus eliminating potential bottlenecks at the stationary packing stations.

Figure 6: Mobile packing station (Specter, 2015)

2.1.3.2 Pitfalls to Avoid When Designing a Packing Station Layout

Failing to address the importance of the packing process and the design of the station itself can expose a firm to a variety of problems, including injuries, inflated transportation costs and money spent on packing materials that are not necessarily needed (Gooley, 2010). Gooley (2010) describes several pitfalls that should be avoided when designing the packing stations. They are all summarized in Figure 7 and further explained in the following sections.

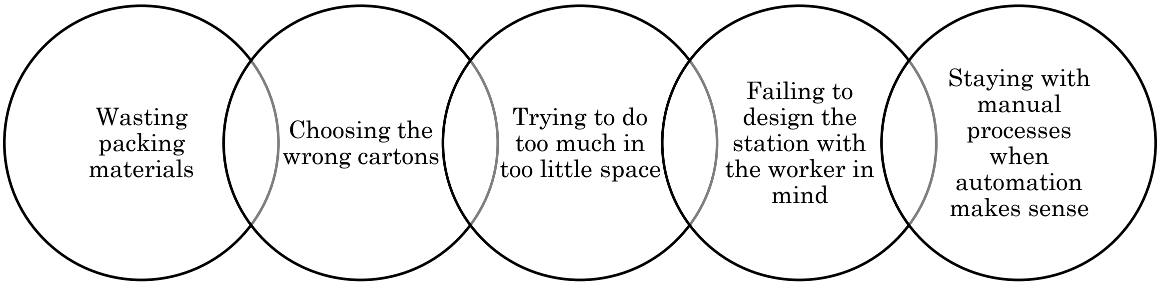

Figure 7: Pitfalls to avoid when designing a packing station (Gooley, 2010)

2.1.3.2.1 Wasting Packing Materials

When selecting packing materials for a given shipment, packers often need to make their best guesses as to how much material they need. This can prove to be very costly since not using enough material could result in product damage, but using too much results in avoidable expenses for the company. An automated dispenser with presets for specific types of products and box sizes can provide more control over the amounts of material that are consumed.

2.1.3.2.2 Choosing the Wrong Cartons

Shipping items in the wrong sized cartons can lead to enormous waste and inefficiencies. Shipping a box that is too big means that the company will be paying to ship air. If the packer initially chooses a box that turns out to be too small, the packer will have to remove the items and repack them, ultimately slowing down throughput in the packing process. Carton selection errors are common, and packers select the wrong box about 25 percent of the time. To avoid these problems, computer-aided carton selection can help. When automation is not an option, careful training of packers and regular refreshers on how to choose the appropriate carton are required.

2.1.3.2.3 Trying to Do Too Much in Too Little Space

Trying to do multiple tasks in a limited area of space may save space, but creates inefficiencies and interference with workflow. If there is a limited amount of space, bulky and static equipment should be avoided. Packing stations that use bubble on a roll takes up a lot of space. Instead, equipment that can follow the operator or be pushed out of the way, like movable carts, should be used.

The long-term needs of a company must also be considered when setting up packing stations. As new products and carton sizes are often added along with business growth, enough space needs to be left to permit the adding of new packing stations or the expansion of existing ones.

2.1.3.2.4 Failing to Design a Station with the Worker in Mind

Ignoring the ergonomics of the work will put the employees at risk for short-term or even permanent injuries. To reduce the risk of back injuries, materials in the packing stations must be stored at the appropriate height. The packers should always be working at the same height level. If workers have to turn, twist, bend or reach to get at supplies, the packing station should be reconfigured. If the packer needs to carry the box after packing it more than a few paces, lift it high or place it down low, carts or conveyors to move boxes to the shipping area should be considered. One aspect that is often overlooked in packing station design is the need to accommodate packers of different sizes. Packing stations can be comfortable for tall men, but physically challenging for their shorter counterparts. Tables and dispensers that allow packers to adjust the height are preferred. A padded floor mat can also help to ease back and leg strain.

2.1.3.2.5 Staying with Manual Processes when Automation Makes Sense

Today, it is possible to buy a machine for almost every packing task: box makers that build cartons around an item, dunnage and void fill dispensers, automatic label printers and applicators, box closers and sealers, and more. When determining which packing activities to handle manually and which to automate, volume and speed requirements must be reviewed. There need to be high enough volumes to justify the cost of equipment. The complexity of products also comes into play. For companies that have a large product portfolio with varied shipping characteristics, machines that weigh and measure items and then select an appropriate box can provide high returns. Another aspect to consider is the likelihood of human errors and the potential cost of such mistakes. Automation can boost accuracy and consistency in quality checks at the packing station.

2.2 Lean Warehousing

2.2.1 Lean

Lean thinking is a business methodology and a concept for waste minimization (Chronéer & Wallström, 2016). It originated from Japanese manufacturing techniques and TPS but was popularized in 1990 and has now been applied within many industry types and to all aspects of the supply chain (Chronéer & Wallström, 2016; Melton, 2005). The lean philosophy is founded upon three principles: the identification of value, the elimination of waste and the generation of value to the customer (Melton, 2005). The philosophy is based on "Kaizen", a Japanese term for continuous improvement (Dotoli et al., 2015), as opposed to "Kaikaku" that represents radical change (Gåsvaer & von Axelson, 2012). A process for how to implement 'Lean thinking' is summarized in Figure 8.

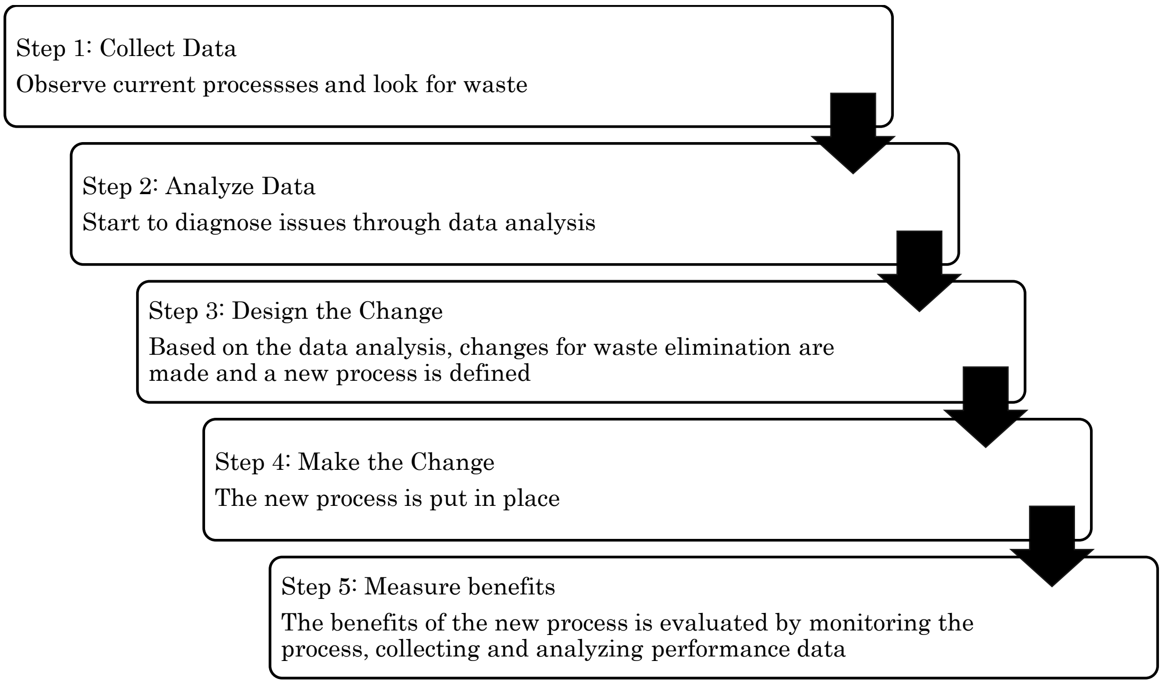

Figure 8: Summary of a Lean implementation process (Melton, 2005)

2.2.2 The Eight Warehouse Wastes

Hines & Rich (1997) propose seven commonly accepted wastes within Lean, initially proposed by TPS: overproduction, waiting, transport, inappropriate processing, unnecessary inventory, unnecessary motion and defects. These were originally stated in a production environment in the automobile industry. Jones (1995) later introduced the TPS philosophy to a warehouse environment. To better fit a distribution setting, he retitled the seven wastes as: faster-than-necessary-pace, waiting, conveyance, over processing, inventory, unnecessary motion and correction of mistakes (Hines & Rich, 1997). In addition to these, several studies have later recognized an eight waste: underutilization of people's skills and expertise (Martin & Osterling, 2014; Salhieh, 2018). A description of each warehouse waste can be found in Table 2.

Table 2: Description of the eight warehouse wastes (Hines & Rich, 1997; Jones, 1995; Martin & Osterling, 2014; Melton, 2005; Abushaikha, 2018)

Faster-than-necessary-pace	Is the purchase or production of goods or services ahead of demand. In a warehouse environment, this is translated into performing warehouse functions to soon or before a customer order has been placed, which can lead to unnecessary congestion.
Waiting	Occurs when employees are free to continue their work but are not allowed to do so due to the unavailability of products, machines or the system. Waiting can lead to underutilization of people and other resources.
Conveyance (Traveling)	Is the non-value adding movement of products, workers and forklift operators, occurring when people or equipment need to move more than necessary to perform a process.
Over processing	Over processing occurs when a process is solved by applying too complex solutions or performing it through too many steps than what would have been necessary. This includes multiple scanning of barcodes, using equipment with unnecessary additional capacity, unnecessary inspection of picked orders, multiple quality checks and unnecessary packaging.
Inventory	Overproduction upstream or inappropriately sized safety stocks can lead to excess inventory in the warehouse. Although the inventory that is prepositioned to buffer against common variation is necessary, the surplus inventory adds no value to the customer but only ties up cash and other resources. It leads to lower availability of storage space and decreased productivity amongst the workers.
Unnecessary motion	Avoidable stretching, bending and lifting by employees. It will occur in cases when inventory is not stored at the appropriate level.
Correction of mistakes	Picking the wrong item or quantity and shipping incorrect orders can result in returns that need to be processed. To reduce the waste of rework and defects, quality should be built into the warehouse processes to prevent the passing on of errors, which is more costly than doing things right from the start.
Underutilization of people's skills and expertise	Not using the employee's full abilities and knowledge as they are equipped with experience and able to provide valuable ideas for improvement.

2.2.3 Benefits of Lean

Lean warehousing is seeking to optimize the use of warehouse resources and activities by the reduction or elimination of waste (Abushaikha, 2018). Some benefits with Lean include decreased lead times, reduced inventories, improved knowledge management and a decreased number of errors (Melton, 2005).

According to Sharma & Shah (2016), studies show that Lean contributes to significant cost reductions, improved staff productivity and higher quality levels. Proper practices for waste reduction are expected to increase a firm's market share and improve its competitive position.

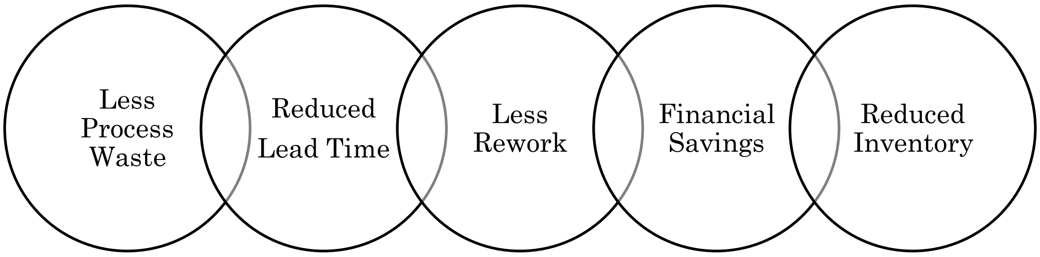

Figure 9: Some of the benefits of Lean (Melton, 2005)

2.3 A Proposed Framework for Lean Warehousing

Lean warehousing is based on the principle that warehouse improvements can be achieved through the application of Lean tools and concepts (Mustafa et al., 2013). There are many Lean tools to support the different steps of Lean implementation (Melton, 2005). Nevertheless, they are usually applied individually and few take advantage of synergies by combining different methods (Cagliano et al., 2018). Bittencourt et al. (2019) argue that in what ways a company should implement the philosophy varies with the business context. However, among the tools of the Lean methodology, some have gained greater acceptance and are used more frequently by companies than others.

Although the literature points out the associated benefits and need for Lean warehousing, the available literature on the subject is mainly academic and there are few works on implementation experiences (Mustafa et al., 2013; Cagliano et al., 2018). Mustafa et al. (2013) recognized that there was a need for developing a more practical approach and a road map for the implementation of Lean tools in warehouse operations. To contribute to closing the identified research gap, Mustafa et al. (2013) propose a framework to control waste and increase efficiency in warehouse operations by integrating a set of different Lean tools. The framework suggests an approach for waste analysis and the application of Lean tools for warehouse operations. Cagliano et al. (2018) argue that by relying on more than just one tool, it is possible to perform the analysis of a warehouse from multiple perspectives. Consequently, better solutions can be found.

The steps of the proposed framework are shown in Figure 10. As proposed by Mustafa et al. (2013), the first step is to identify and classify warehouse waste by combining the application of the seven (or eight) wastes categorization with the 5Ws tool. The 5Ws is adopted to explore the cause and effect relationships with the purpose to determine its root causes. The objective of the initial step is to identify different sources of waste and determine what, when, where, why and by whom an activity within a process suffers from waste (Cagliano et al., 2018). In accordance with Mustafa et al. (2013), actions to reduce the waste that was identified in the first step are devised through the 5S technique as the second step within the framework. A tool that supports the implementation of the improvements and which can quantify its associated effects is also needed. Therefore, the third and final step of the framework relies on VSM. A more exhaustive description of the framework's Lean tools is outlined in the following sections.

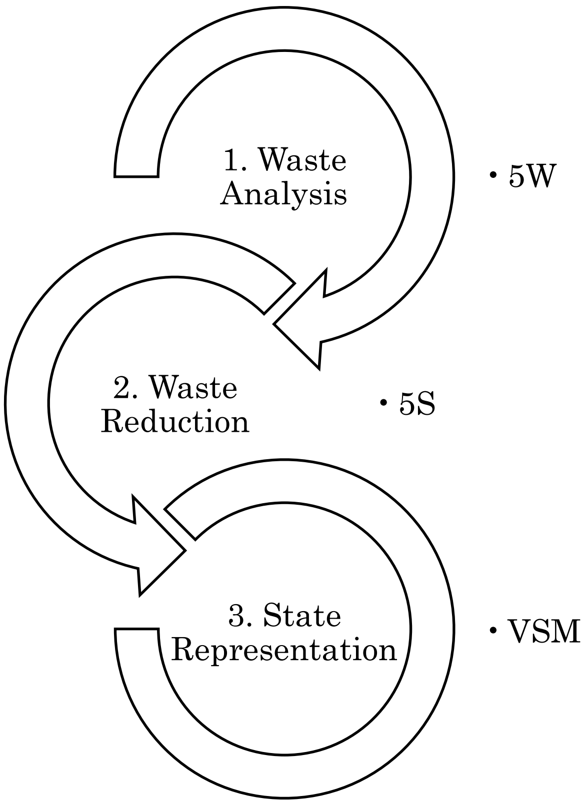

Figure 10: The steps of the proposed framework (Adapted from Cagliano et al., 2018)

2.3.1 Value Stream Mapping

One simple but valuable tool that has emerged as the preferred way to implement a Lean philosophy is VSM (Chen et al., 2013). It is a technique used to visually map and show all actions in a process, both value-adding and non-value adding, that are required to bring a product through the flow in a way that highlights opportunities for waste elimination (Dharmapriya & Kulatunga, 2011; Dotoli et al., 2015). In line with Hines & Rich (1997), an achieved understanding of the current state makes it possible to identify which activities that are value-adding and which ones that are considered pure waste. The activities that are mapped can be grouped into three different categories:

- Non-value adding (NVA)
- Necessary but non-value adding (NNVA)
- Value adding (VA)

Waste constitutes the first category, NVA, including activities that do not add any value to the customer and which are not necessary for the organization to operate its business. These activities should be eliminated. The second category of activities, NNVA, may be a source of waste but is necessary within the current operations.

Forno et al. (2014) claim that Lean warehousing implementation starts with VSM. The main goal is to observe how the material flows from the raw material to the final customer in real-time. By the use of symbols, the processes can be clearly visualized, thus visualizing the occurring waste. VSM is a valuable tool for understanding the status of a current process and identify improvement opportunities. It allows for a broader view of an entire flow, making it easier to identify wastes. Although little research has employed VSM for Lean warehousing (Dotoli et al., 2013), VSM is found to be useful in a warehouse setting as it is essential for the identification of improvement areas (Wessman & Bärring, 2014).

According to Rother & Shook (1999), VSM is conducted in four steps: selection of a product family, construction of a current-state map, construction of a future-state map, and the development of an action plan. The steps are further described in the following sections.

2.3.1.1 Select a Product Family

As all products are not equally important from the customer's perspective and the process of drawing out the flow for every product in one map would be too complex, VSM needs to be performed with a focus on one product family at a time. Ultimately, the starting point is to determine the product family at focus. A product family represents a group of products that will pass through similar processing steps. In the example illustrated in Table 3, product A and C belong to the same product family because they pass through the same processes within the value stream. Typically, the product family that shows the most potential for improvement should be selected.

Table 3: Product family matrix (Adapted from Rother & Shook, 1999)

PRODUCT/PROCESS	1	2	3	4
A	✓		✓	✓
B	✓	✓		
C	✓		✓	✓
D	✓	✓	✓	✓

2.3.1.2 Map the Current-State

Before any improvements can be made, the first step is to gain an understanding of the current state for the selected product family by gathering information on the actual shop floor (Rother & Shook, 1999). Gemba walks, further described in section 2.3.1.5, can be used at this stage (Dotoli et al., 2015). The information that is collected will provide a basis for the development of a future-state (Rother & Shook, 1999).

According to Rother & Shook (1999), the mapping can be performed on different levels for the chosen product family. It can be performed across companies, multiple plants, a single plant or at a process level. A first step is hence to determine the boundaries of the processes and which level that will be mapped.

A set of symbols is used to represent processes and flows. Some of the common icons and an example of a current-state map are illustrated in Appendix B. As data from observations of the current-state processes have been recorded on the map, the current value stream can be summarized. A timeline is drawn to visualize the product lead time, meaning the time it takes for the product to make its way through the shop floor. Then, the value-adding times are compared to the total lead time.

2.3.1.3 Map the Future-State

Making a current-state map is a waste of time and the required effort unless the developed map is used to create and implement a future-state map where the highlighted sources of waste have been removed. The main goal is to build a chain of processes where each process is linked to the customer by a continuous pull flow.

2.3.1.4 Achieving the Future-State

VSM is only a tool and unless you achieve the future-state map that you have developed, the maps lose their value. Normally, it will not be possible to implement the entire future-state map at once, but it requires to be implemented in a series of steps. Lastly, plans for achieving your future-state map needs to be considered in a Value Stream Plan which breaks the implementation into smaller steps.

2.3.1.5 Gemba

Gemba is one of the techniques of Lean, founded upon the idea that problems need to be encountered at the site of action in order to be resolved (Imai, 2012). As stated by Dotoli et al. (2015), the Gemba philosophy recommends managers to spend more time on the plant floor, where real action occurs, rather than in their office. Gemba is a companion approach of VSM and can be useful to map the different processes for the product family at study. Imai (2012) describes a Gemba walk to be a very useful tool to gain an understanding of the daily activities that are carried out within an organization. During a Gemba walk, researches will simply go to the actual shop floor and gather information through observations.

2.3.2 5Ws

The 5Ws tool is illustrated by providing an example of how it was applied for the receiving process in a warehouse by Cagliano et al. (2018).

Table 4: Example of a 5Ws analysis output for the receiving process in a warehouse (Cagliano et al., 2018)

What	Moving materials around the unloading area looking for an empty space to place them
When	Once items are unloaded from the truck
Where	In the unloading area

Why	The unloading area is very full and it is difficult to find an empty space. There is a lot of materials that need to be put away and this creates a bottleneck in the unloading area
Who	Warehouse staff

2.3.3 5S

Besides VMS, which is the most adopted technique in the so-called “Lean Toolbox”, 5S can be applied as a step to achieving Lean warehousing (Cagliano et al., 2018). In accordance with Chiarini (2012) and Malavasi & Schenetti (2017,) the 5S tool is divided into five phases, each named after a Japanese term starting with the letter “S”: *Seiri* (Sort) emphasizes the separation of useful and useless activities within a process in order to sort and remove everything that is not useful for that particular process; *Seition* (Set), refers to the reorganization of the workplace, putting tools, equipment and everything that is useful in an accessible place; *Seisio* (Shine), means to clean the workplace namely by keeping the area clean; *Seiketsu* (Standardize) emphasizes the standardization of activities by having instructions that are easy to understand as well as by creating consistency in the way tasks and procedures are carried out; *Shitsuke* (Sustain), means respecting the predefined standards and sustaining the tidiness throughout the process.

2.4 Industry 4.0 and Warehouse Automation

Warehouse automation can be defined as *“the direct control of handling equipment producing movement and storage of loads without the need for operators or drivers”* (Baker & Halim, 2007). It includes equipment such as AS/RS, AGVs, picking robots, vertical carousels, conveyorized picking systems and A/SS (Baker & Halim, 2007; Wyland, 2008).

Taliaferro et al. (2016) describe how connected technologies have emerged throughout the distribution value chain in recent years. The marriage of digital and physical systems, known as Industry 4.0, has impacted how goods are moved, stored and distributed. Industry 4.0 technologies can pave the way for a more flexible, agile and efficient DC, enabling automated systems to take on warehouse tasks more efficiently, while interacting and working alongside humans. Kembro & Norrman (2019) report that the warehouse processes that are most likely to be highly automated in the next coming years are picking, sorting, packing and put-away. Today, about 40 percent of companies that were included in a study had automated their packing process to some extent. In five years, this number is predicted to exceed 90 percent.

In the following sections, some of the advantages and disadvantages of warehouse automation will be summarized. Some ways in which the packing process could be automated are described. The last section will be dedicated to describing the benefits of A/SS, which is one of the technologies that could be leveraged in the sorting and packing process apart from those that already have been described in the previous sections.

2.4.1 Reasons to Automate a Warehouse

As stated by Azadeh et al. (2017), warehouse operations tend to be labor-intensive as a great number of items are handled in large facilities, where high volumes of goods are unloaded, stored, moved and loaded daily. It is repetitive and causing poor ergonomics for the warehouse workforce. For these reasons, warehousing systems and processes are key candidates for automation. Widespread implementation of IT and high levels of automation provides new opportunities to improve warehouse operations (Gu et al., 2007). Altogether, these systems will gradually automate warehouses (Azadeh et al., 2017). The benefits of warehouse automation vary with each use case, including increased throughput, a reduction of waste, improved ergonomics for the warehouse staff and higher customer service levels (McKinsey, 2017).

According to Wyland (2008), the amount of human effort that is required for material handling has been reduced by the use of automation to move products through the warehouse over the last two decades. Focus is placed on turning the warehouse workforce into a value-adding part of the value chain as automated MHE takes on responsibility for the movement of products, reducing the need for humans to engage in such non-value adding activities. Hence, automated MHE provides opportunities to leverage the warehouse workforce. Automated MHE can support warehouse optimization by shortening turnaround times and decreasing labor costs as it can eliminate the requirement for employees to travel around in the warehouse (Myers, 2015). Traveling is considered to be a wasteful warehouse activity that should be reduced to the extent that it is possible (Hines & Rich, 1997; Martin & Osterling, 2014).

Kembro & Norrman (2019) conclude that even though automation solutions often require significant investments, many companies are expecting positive ROIs on their investments as a result of more efficient flows and more cost-efficient materials handling. Apart from scale efficiencies, the requirements for sorting, package handling (folding, packing, labeling), ergonomics and safety are driving factors for automation. Ergonomic and safety are two important concerns, where automation can decrease the need for heavy lifting.

It can be concluded that automation can be used to accommodate growth, reduce costs and improve customer service, as well as to improve productivity and reduce staffing levels (Baker & Halim, 2007).

2.4.2 Reasons Against Automation

Although warehouse automation can provide many advantages, it also faces some challenges (Kembro & Norrman, 2019). The decision to automate a warehouse is viewed as a strategic decision that will have a long-term impact on the facility (Baker & Halim, 2007). In some cases, automation results in a decrease in flexibility as some processes, once automated, become more difficult to change (Bell & Orzen, 2011). Some systems can require high standardization of processes and products as the system adaptability is limited (Taliaferro et a., 2016). This also impedes the continuous improvements of such processes (Bell & Orzen, 2011). However, Taliaferro et al. (2016) claim that there is also evidence of increasing flexibility in emerging technologies. There is a trend towards smart automation which is highly flexible in terms of product handling and which can be adapted to a variable demand and interact with other systems as well as other human employees.

As found by Kembro & Norrman (2019), a larger product assortment with a high variety in product characteristics can make it more difficult to take advantage of warehouse automation as solutions are often sensitive to changes in product characteristics and size. As new products are introduced, with diverse material handling needs, it can be difficult to adjust automation solutions accordingly. High demand variations also make it more complex to design an automated solution, as the solution then must be designed with the ability to handle the peaks. Along with investments in automated solutions, it also becomes important that the packaging from suppliers is suitable for the new, automated system. Another aspect that needs to be addressed is the staffing issue. Automation will partially change the profile for warehouse workers. Instead of being dedicated to the handling of goods, the need for personnel that can design and maintain automation solutions will increase.

Baker & Halim (2007) mention that warehouse automation is often viewed as being cost-effective in large volume facilities. The main decision criterias for automating processes are the potentials of labor cost reductions, increase in output and improved service levels. Indigo (2017) states that although full warehouse automation can deliver significant returns for high-volume tasks, the high investment costs of such systems entail that many small and medium-sized enterprises do not have the financial funding, or high enough volumes that would support a move to a fully automated warehouse. Before deciding to invest in automation, considerations must be taken in terms of volume, size and the diversity of orders in the processes that are candidates for automation. A partial-automation strategy that is common involves integrating technology such as A/SS, weighing scales and conveyors with the existing WMS. Standalone processes can be optimized, for example by installing a conveyor in a key area, without having to re-engineer the entire warehouse operations. Partial automation will also be less costly to implement and ensure flexibility.

As reported by Baker & Halim (2007), the IT system will be a critical part as IT changes normally have to be made in any automation project. Most projects need to make some modifications to the ERP system, and about half of automation projects also require a new WMS.

2.4.3 Automated Packing Stations

Packing stations can be equipped with varying levels of automation for even higher gains in throughput (Specter, 2015). According to Taliaferro et al. (2016), DCs are increasingly expected to offer supply chain capabilities such as value-adding services, e.g. product assembly, product labeling and repackaging. In response to this, several companies are working on automating outbound packaging, shipping and gift wrapping through the use of semiautonomous machines for value-added services.

Packing stations can be integrated with the WMS and WCS (Specter, 2015). Final packaging machines using sensor detection technology with automatic format adjustment capabilities can detect changes in product characteristics such as size and shape and notify the WCS the packaging configuration that is needed, ensuring that the correct packing box is being used to pack in (Taliaferro et al., 2016). Specter (2015) suggests that when pickers deliver the items to the packing station, the sortation process can be supported by having a monitor displaying pictures that give work instructions about which item that goes in which box. For high-volume warehouse operations, fully automated packing stations, which integrates software, conveyors and related in-line equipment such as a checkweigher, are an option for packaging. By adding product cubing data, the system can determine the correct packaging carton size. The system can also synchronize the printing and applying of packing slips and shipping labels.

Figure 11: Automated packing stations (Specter, 2015)

2.4.4 Automated Sorting Systems

A system within a DC that provides opportunities to improve both costs and throughput times is an A/SS (Meller, 1997). Consequently, many supply chains apply fully-automated sorting systems as one of the basic components of their distribution processes (Boysen et al. 2018b). Properly designed, a sortation system can save much of the unproductive travel time in a warehouse (Johnson & Lofgren, 1994). Along with increasing demand and higher material flows, it can even be concluded that an A/SS will be decisive (Sun et al., 2018).

An A/SS has applications in a variety of contexts. The typical applications of A/SS in warehouses are twofold (Boysen et al., 2018b). As mentioned in section 2.1.2.3, order consolidation processes are inevitable whenever orders are assembled through zoning, batching or wave policies (Boysen et al., 2018a). These policies lead to an intermix of items, which calls for an additional sorting process of items into customer orders (Boysen et al., 2018b). Although some warehouses apply a manual sorting process through the use of put-walls, it is more common that this process is executed by the use of fully-automated sorters (Boysen et al., 2018b; Boysen et al., 2018a). According to Boysen et al. (2018b), an A/SS can be used to split the collected batches and accumulate the customer orders before packing each order into its shipping container. A layout of such a system is depicted in Figure 12. In addition to this, once each customer order is packed into its shipping container, an A/SS can also sort the packages by shipment. In the shipping area, another A/SS will direct the stream of packages by the use of conveyors that directly transports the packages to different outbound trailers based on the packages' destination or transport provider, e.g. DHL or UPS. A layout for such a system is illustrated in Figure 13.

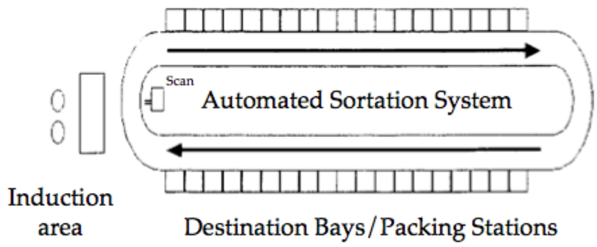

Figure 12: Layout of a split-case sorting system (Russel & Meller, 2003)

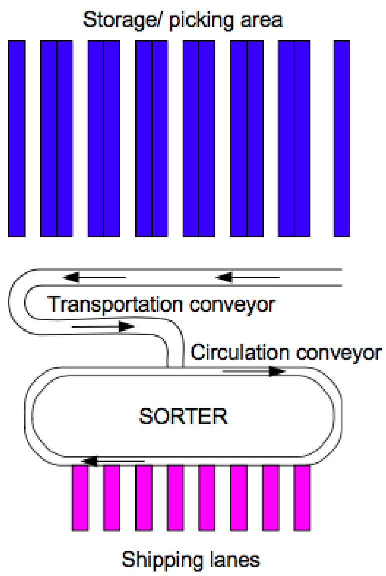

Figure 13: Layout for a shipping sorter (de Koster et al., 2007)

In line with Sun et al. (2018), an A/SS can improve productivity and save the cost of labor. Automated sorting systems are being used instead of manual sorting systems as they are more reliable and can operate at a lower cost. Replacing the manual sorting method with an automated system can increase efficiency by about 70 percent. However, it comes with high investment costs. Russell & Meller (2003) state that a technologically advanced A/SS is both large and expensive. As a consequence, the implementation of it must be feasible and consideration needs to be taken with respect to throughput. The size of the system that is required and the cost of the employees that are needed to operate it needs to be included when analyzing if it would be more cost-effective and should replace manual sortation. Russell & Meller (2003) investigated the benefits of A/SS compared to a manual sorting process and propose a descriptive model that can be used to investigate whether a warehouse should automate the sortation process or keep it manual by comparing the costs of alternatives.

2.5 Industry 4.0 and Lean Thinking

As concluded by Malavasi & Schenetti (2017), Industry 4.0 conveys a future in which companies will increase efficiency and competitiveness through the interconnection and cooperation of machineries, people and information. Modern industrial technologies, ranging from software to automation, will enable radical improvements.

As of today, Lean is still the most established driver for reaching high-level efficiencies within companies (Womack et al., 1990). With the advent of Industry 4.0, researchers are questioning whether these two concepts will co-exist and what the impact of the interrelation between them will be (Rossini et al., 2019). Although some may argue that Lean and Industry 4.0 represent "two opposing camps" (Piszczalski, 2000) and that Lean does not cope with an automated Industry 4.0 initiative (Malavasi & Schenetti, 2017), others state that Industry 4.0 could be considered as "Lean's next level" (Jones, 2016). Malavasi & Schenetti (2017) confirm that some authors support the idea that Industry 4.0 is a natural evolution of Lean principles, being used to make Lean reach its full potential. As such, Industry 4.0 can enable companies to optimize the value-adding activities to reduce waste.

Bittencourt et al. (2019) state that even though the two concepts appear to be very different, they share the same objectives: cost reduction and increase in productivity. Lean thinking aims to achieve these objectives through the elimination of waste and a mindset of continuous improvement, whereas Industry 4.0 seeks to do so by the exploration of new technologies. Prior research shows that Industry 4.0 and Lean are mutually supportive and positively related. Industry 4.0 supports and strengthens the implementation of Lean thinking in companies and Lean methods have an enabling effect on the implementation of Industry 4.0. Technologies of Industry 4.0 can support Lean implementation by employing technologies to reduce human effort and facilitating people's work. In return, simplified and waste-free processes achieved by a Lean enterprise simplifies efforts to automate and digitize processes through the implementation of new technologies. By combining the two approaches, more effective improvements can be realized.

2.6 Framework for Data Collection and Analysis

The framework graphically explains the main concepts that are to be studied and the presumed relationship between them. The framework serves the purpose of giving an overview of the areas that will be relevant in the data collection process as well as the subsequent analysis of it.

As depicted in Figure 14, the data collection process initially serves the purpose of mapping the current state of the packing process. For this, an understanding of the design of the outbound processes and packing station layout will be fundamental, as these are affecting the current state of the packing process, as well as the changes to it that can be made as the future-state is under development. Wastes are identified through observations, before proceeding to the analysis. In the analysis, the tools from the proposed framework are applied: 5Ws, 5S and VSM. As the future state of the packing process is developed, considerations are taken to the size and time distribution of flows as well as physical layout constraints. The new packing area layout that is developed should include some parameters. These include how many packers and packing stations that will be necessary to handle the flows, how the consolidation area and packing stations will be designed, where packing of BG and DG will take place as well as where the storage of materials and shipping pallets should be located.

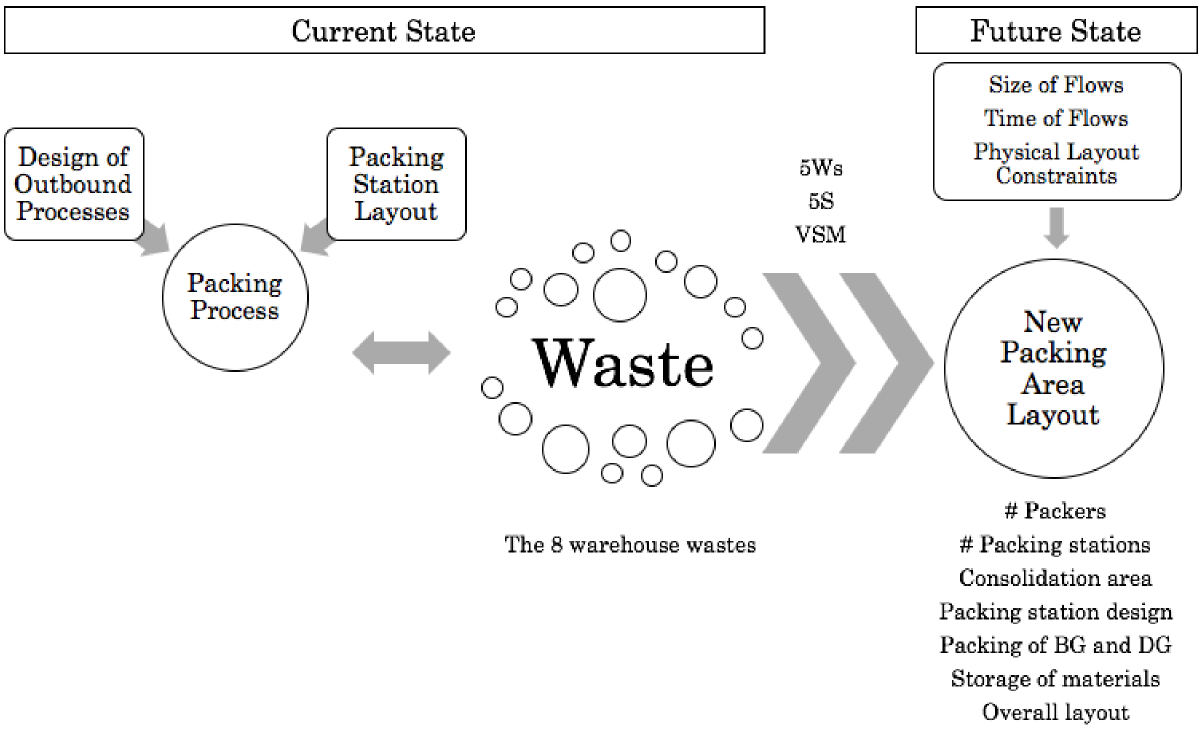

Figure 14: Framework for data collection and analysis for the purpose of the study

Chapter 3

Methodology

The following chapter contains an overview of the research methodology. The chapter aims to explain the chosen approach and provide a background for how the research is conducted. It explains in detail the structure of data collection methods and how both credibility and validity are assured throughout the study.

3.1 Outline

There is an infinite number of approaches, strategies and methods that can be used when undertaking any research project (Saunders et al., 2009). Some situations may indicate one preferred way of doing research (Yin, 2003). Of equal importance, there is not always one best way to tackle a research project, as there may be overlaps between the distinctive characteristics of each choice (Saunders et al., 2009; Yin, 2003).

This master thesis will be executed through a descriptive and exploratory case study research method using a single organization, AL DC Tumba, as the case. Both quantitative and qualitative research methods will be used. Observations, interviews and secondary data will be the methods used for data collection. In the following chapters, each of these choices will be explained and motivated.

3.2 Research Purpose

In accordance with Saunders et al. (2009), the research purpose is commonly classified into being exploratory, descriptive or explanatory. However, a research project can sometimes have multiple purposes. An exploratory study aims to seek new insights and ask questions in order to assess a phenomenon in new ways. It is particularly useful when the aim is to clarify an understanding of a problem. Usually, an exploratory study is conducted through literature reviews, interviewing experts and conducting focus group interviews. A descriptive research aspires to portray an accurate picture of a phenomenon. It can be done as a forerunner to exploratory research or, more often, as part of explanatory research to gain a better overview before any data is collected. Explanatory research projects establish causal relationships between different variables by studying a situation or a problem.

The purpose of this research is to identify occurring waste in the packing process in a particular warehouse. The research also intends to explore how the layout could be redesigned to reduce warehouse waste. With this twofold purpose in mind, it can be concluded that the research would be classified as having a descriptive purpose, with the objective to describe the current state of the packing process. The second part of the purpose also indicates that the research purpose can be regarded as exploratory. In accordance with the literature, the first part of the research, aiming to answer RQ1, is descriptive, and the second part, aiming to answer RQ2, is of more exploratory character.

3.3 Research Strategy

3.3.1 Why a Case Study is Chosen

The case study is defined as *"a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real-life context using multiple sources of evidence"* (Robson, 2002).

Yin (2003) distinguishes between five major research strategies: experiment, survey, archival analysis, history and case study. Each of them can be used for all three purposes: exploratory, descriptive, or exploratory. Each research strategy is accompanied by different advantages and disadvantages, and the choice of strategy will depend on three conditions: the type of research question that is asked, the control that the investigator has over behavioral events and whether the study focuses on contemporary or historical phenomena. Generally, case studies are preferred when "how" or "why" questions are posed about a contemporary set of events within a real-life context over which the investigator has little to no control.

Table 4: Situations where the different research strategies are relevant (Yin, 2003)

STRATEGY	TYPE OF RESEARCH QUESTION	REQUIRES CONTROL OF BEHAVIORAL EVENTS	FOCUS ON CONTEMPORARY EVENTS
Experiment	how, why?	Yes	Yes
Survey	who, what, where, how many, how much?	No	Yes
Archival analysis	who, what, where, how many, how much?	No	Yes/No
History	how, why?	No	No
Case study	how, why?	No	Yes

As can be interpreted from Table 4, a case study is the preferred choice of strategy when studying contemporary events where the relevant behaviors cannot be manipulated. The case study shares many common techniques with a history but adds two sources of evidence that the history does not: direct observation of the events at study and interviews of the persons that are involved in such events. The case study's strength lies in its ability to deal with a variety of evidence, e.g. documents, interviews and observations.

The case study is used in many situations to contribute to the knowledge of individuals, groups, organizations and society. Its method allows researchers to retain comprehensive and important characteristics of a real-life context. Such contexts include organizational processes. As this research involves the investigation of a specific process within the real-life context of a particular warehouse, the case study is chosen as the appropriate research strategy. This is further justified as one of the research questions is of "how"-character.

Case studies should not be confused with “qualitative research”, as they can be based on a combination of both quantitative and qualitative evidence. For this study, a combination of them will be used, further discussed in section 3.4.4.

3.3.2 Case Study Design

After identifying the case study as the preferred research strategy for a research project, the next step is to design the case study. For this purpose, a research design will be necessary. A research design is a logic that links the data to be collected and the conclusions that can be drawn from it to the research questions.

3.3.2.1 Defining the Case Study Design

Every empirical research has a research design. It is a logical plan for how to get from the initial set of research questions that are to be answered to some set of conclusions. Between these two, there are several steps that need to be completed and which must be designed properly. Each of the steps included in the case study design, see Figure 15, will be further described in this section.

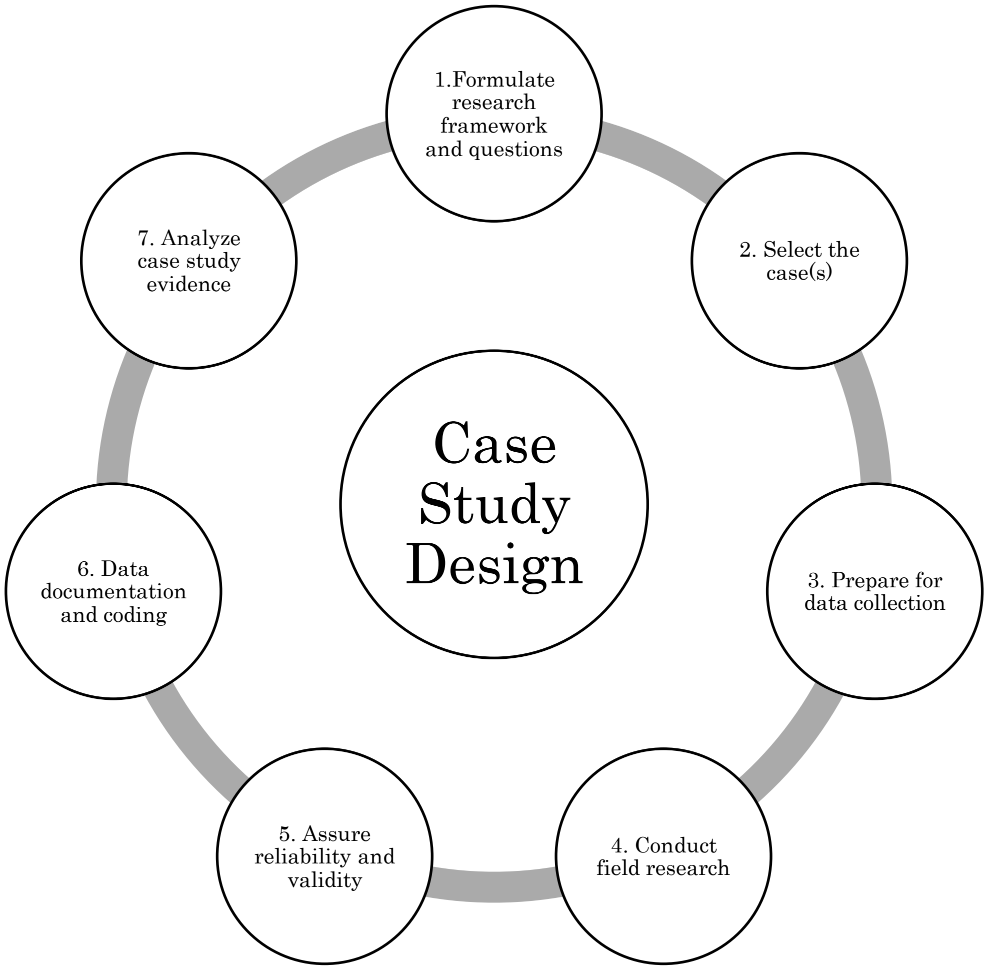

Figure 15: Case study design (Voss et al., 2002; Yin, 2003)

In accordance with Voss et al. (2002), the starting point of the study is the research framework and questions. The construction of a conceptual framework for the underlying research serves the purpose of providing a prior view of general concepts that are intended to be studied and the relationship between them. Such a framework explains graphically the main concepts that are to be studied and the presumed relationship between them. Yet another vital step in designing a case study is formulating the initial research questions. When conducting case research it is not uncommon that the research questions evolve or gets modified.

The second step in designing a case study is determining how many cases that are to be included in the study, and then select the case or cases (Voss et al., 2003). Yin (2003) generalizes between four types of designs based on a 2x2 matrix, displayed in Figure 16. A primary distinction between case studies is the one between single- and multiple-case designs. This case study is performed as a single-case study, with AL DC Tumba as the single case. The single-case study is appropriate under several circumstances. One is when the objective of the single case is to capture the circumstances and conditions of an everyday problem. The case study may represent a typical project, amongst other projects. These are the circumstances under which this case study was initiated.

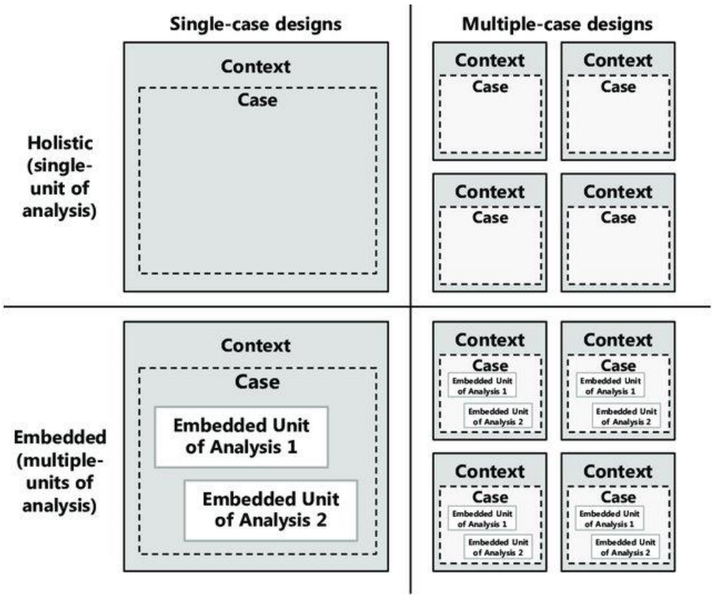

Figure 16: Basic design types for case studies (Yin 2003)

In line with Voss et al. (2002), research instruments and protocols are implemented for the collection of data as the third step. For the majority of case studies, interviews are the primary source of data. The reliability and validity of the data will be enhanced by using a well-designed research protocol that contains the research instruments, the procedures and rules that should be used when utilizing the instruments, and indications of who or from where information is to be sought. The set of questions to be used in the interviews represents the core of the protocol. When designing the research, the trade-off between efficiency and richness of data must be considered. By asking the same set of questions to a number of respondents, the reliability of data is enhanced. On the other hand, this can be very time-consuming.

One of the underlying principles for data collection in case studies is that of triangulation, meaning that a combination of different methods is used to study the same phenomenon. The data collection methods used in this study are further described in section 3.4.

Once data has been collected, it should be documented. The validity and reliability of the data should also be assured. How the validity and reliability were secured in this research is further explained in section 3.6.

The analysis can be further broken down into an analysis of individual case data and searching for cross-case patterns. Since only a single case is chosen for this study, searching for cross-case patterns will not be relevant and only an analysis of the single case can be performed. The purpose of the analysis is to identify waste and give recommendations for how it could be eliminated through the development of a new layout for the packing area.

3.3.2.2 Unit of Analysis

According to Yin (2003), a component of high importance in the design of a case study is the UoA. The UoA is defined as the entity that will be researched in the study, e.g. an individual, an artifact, a department or a process. The selection of an appropriate UoA can be made when the primary research questions have been accurately specified. If the questions do not lead to a UoA, the questions are either vaguely formulated or too numerous. This will later result in troubles as the case study is being conducted.

A case study may involve more than one UoA. Within a single case study, this occurs when attention is given to a subunit or subunits. If the study concerns a single organization where multiple subunits are examined, it is referred to as an embedded case study. As opposed to the embedded case study, a holistic case study examines only the global nature of an organization or a program.

In this case study, the UoA constitutes of a process within a warehouse, namely the packing process and the consolidation interface between the packing and picking processes. Hence, the study concerns a single organization where a subunit, a DC, is being examined. This puts the study in the lower-left corner of Figure 16. The primary UoA is the packing process. The layout and waste within the packing process make up embedded UoAs.

3.3.2.3 Theory Development

The role of theory development prior to proceeding with the data collection is a point where the case study differs from other related methods. Students wrongly presume that the choice of conducting a case study suggests that they can proceed quickly into the data collection phase and may have been taught to head out into the field as quickly as possible. This could not be more misleading as the field of contacts is dependent upon an understanding of the theory of what is being studied.

The theory development plays an essential part already in the design phase of the case study. The use of theory when conducting a case study can immensely aid in defining the research design and collecting data. Nonetheless, theory development requires time and effort, and can be difficult as not all topics have existing works that are providing guidelines. To overcome barriers for theory development and become aware of the full range of theories that might be relevant, relevant literature to what is studied should be reviewed. A good case study investigator should make the effort of developing a theoretical framework that is as comprehensive as the available literature allows.

3.4 Data Collection Methods

Data for case studies may come from multiple sources of evidence. In fact, a major strength of the case study data collection is the opportunity to use several sources of evidence. However, this also makes the process for data collection more complex when comparing case studies to other strategies. The most commonly used methods are documentation, archival records, interviews, direct observations, participant-observations and physical artifacts. The methods used for data collection in this study are summarized in Figure 17. In the following sections, these methods will be further described.

Observations	Interviews	Secondary data
• Direct observation for pilot study • Direct observations during VSM	• With employees of the picking and packing teams • With managers	• Secondary data from the ERP system, that shows the volume of flows and timestamps for different order statuses

Figure 17: Summary of the relevant data collection methods for the case study

3.4.1 Direct Observations

Direct observations can be made by making field visits to the case study "site". The observations can range from being both a formal or more causal activity of data collection. Observational protocols can be developed and included in the case study protocol. The observant may also measure the incidence of certain events during a certain period of time in the field. The difference between direct observations and the participant-observation technique is that the observant is not assuming any role in the situation at study and do not participate in it in any way.

For this study, direct observations are carried out first as a pilot activity, to get an understanding of the packing process before developing the research design further. Secondly, Gemba walks are done as a part of the VSM. During these observations, the time to pack orders is measured to quantify the value-adding time in the packing process. An overview of the performed direct observations is provided in Table 5.

Table 5: Overview of performed direct observations

WHAT	WHEN	PURPOSE

Pilot Gemba Walk	2019-05-08	Gain an understanding of underlying issues prior to structuring a framework for data collection and theory building
Observations and time study of current-state packing process	2019-05-27, 2019-05-28	Identifying waste, collect data to estimate the packing process time in the current-state
Observations and time study for future-state packing process	2019-06-13, 2019-06-18	Estimating the packing process time without occurring waste
Observations and time study of current-state and future-state packing process for BG stations	2019-06-18, 2019-06-19	Estimating how the packing process time for BG differs from the packing process time for other goods, for both the current-state and future-state process

3.4.2 Interviews

Interviews are one of the most essential sources of case study information. Most commonly, the questions asked in a case study interview are open-ended and the respondents are encouraged to propose his or her insights to a problem. Another type of interview, the focus interview, is more likely to follow a certain set of questions that have been developed beforehand.

Table 6: Overview of interviews

INTERVIEWEE	COVERED SUBJECTS	DATE
Packer	Packing process, utilization of employees skills	2019-05-28
Picker & packer	Picking and packing process	2019-05-28
Team manager for outbound	Outbound processes, staff management	2019-06-03

During the case study, employees at a variety of positions are interviewed, as found in see Table 6. The choice of employees to be interviewed are based on their position as well as their ability to share their ideas on the subject that is being studied. The interview guide for the interviews can be found in Appendix E.

3.4.3 Secondary Data

Saunders et al. (2009) refer to secondary data as data already collected for some other purpose that can be reanalyzed with the purpose of answering the research questions of the study. Even though a majority would automatically think in terms of collecting new, primary, data for the specific purpose, such secondary data can be a useful source from which to answer the research questions.

Yin (2003) states that archival records may be relevant to many case studies. Maps and charts of layouts are examples of records that are included in the study. Moreover, ERP data forms an essential foundation before answering both of the research questions. ERP data is used to quantify waste in the form of waiting times and traveling to collect carton boxes, to find out the number of orders and order sizes that are being packed per day, as well as to estimate the size of different parts included in the new packing area.

3.4.4 Qualitative and Quantitative data

In line with Saunders et al. (2009), a distinction between qualitative and quantitative research can be drawn, as summarized in Table 7. Quantitative data refer to all numerical data, ranging from simple counts such as the frequency of occurrences to data such as prices and costs. Qualitative data refers to all non-numeric data and is associated with more ambiguous concepts, ranging from a short list of responses in a questionnaire to data such as transcripts of in-depth interviews. The distinction between the two forms of data is helpful to understand what is necessary to be able to analyze the data in a meaningful way. Analyzing quantitative data can, for example, be done through creating tables or diagrams and by the use of statistics. During the analysis of qualitative data, the non-standardized and more complex nature of the data will most likely require it to be condensed, categorized or restructured. Most likely, it will be analyzed through the creation of a conceptual framework, formulated before or after the data collection.

Virtually any research undertaken is likely to involve some numerical data. In this study, quantitative secondary data is collected from the ERP system. Moreover, quantitative primary data is collected in terms of quantification of the value-adding time in the packing process by observation and a comparison to the total packing process time. For this study, quantitative data is gathered as secondary data and analyzed through the creation of diagrams. Qualitative data is gathered through observations and interviews. The results, the identified wastes, are then categorized.

Table 7: Distinctions between quantitative and qualitative data (Saunders et al, 2009)

QUANTITATIVE DATA	QUALITATIVE DATA
Derived from numbers	Expressed through words
Collection results in numerical and standardized data	Collection results in non-standardized data that requires classification into categories
Analysis is conducted through the use of diagrams and statistics	Analysis is conducted through the use of conceptualization

3.5 Research Execution

Although the methodology that is applied for this case study has partially already been explained, this section aims to give a more comprehensive overview of how the research was conducted. This is of high importance as a more detailed explanation of the approach will enable a reconstruction of the study and strengthen the reliability of it (Saunders et al., 2009). Figure 18 gives an overview of the four different phases of the research execution. The following section will further describe what each phase involved.

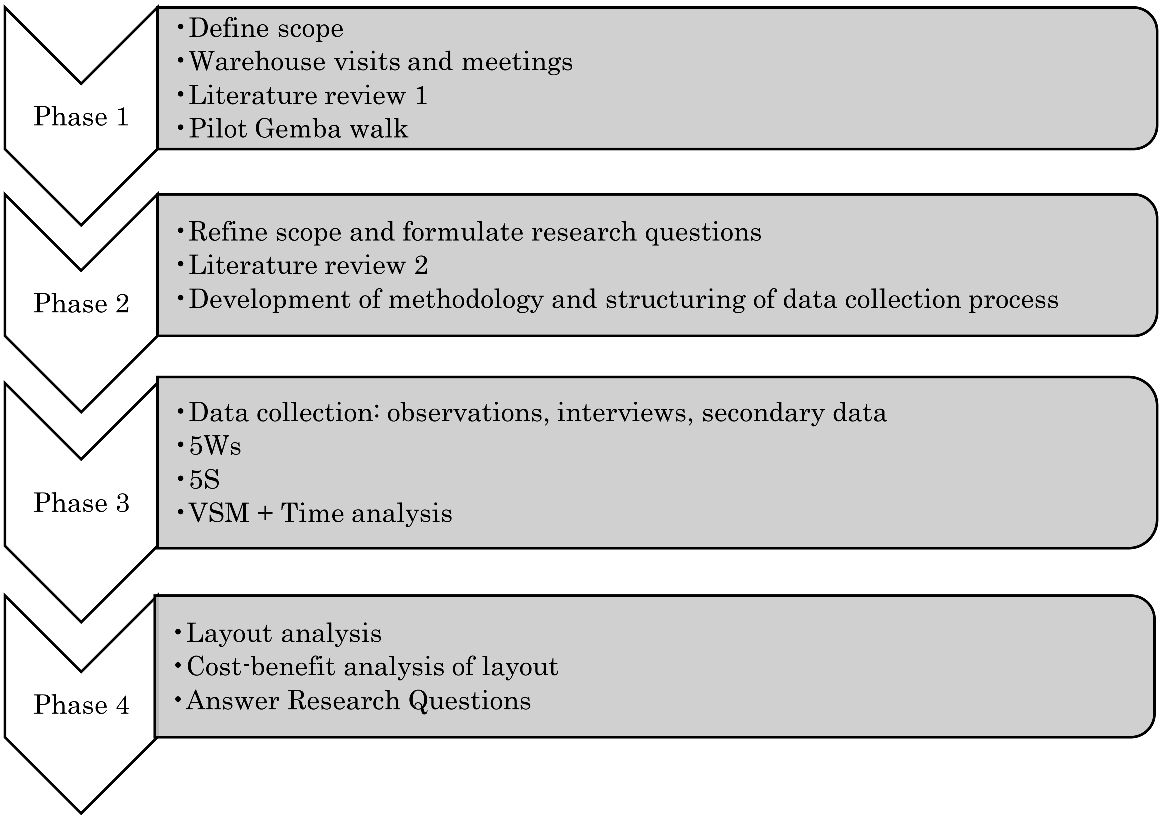

Figure 18: The four phases of the Research Execution

3.5.1 Phase 1

The first phase consisted of building a foundation for the study. As the study was initiated, the scope was defined after several meetings and discussions together with personnel working at AL DC Tumba: Stefan Radonjic (Warehouse Unit Manager), Anders Viklander (Project Manager) and Måns Ribrant (Unit Manager). During the first weeks, time was spent in the warehouse to build an understanding of the material flows and the current situation in the warehouse.

The literature review was commenced. Theory development played an essential role in the design phase of the study and was performed prior to proceeding with the data collection. The majority of relevant literature for the Theoretical Framework was found through LUBSearch, ResesarchGate and Google Scholar. Some of the keywords that were used in the literature review include *Lean, VSM, Lean warehouse, warehouse waste, packing process, packing station, warehouse layout, Lean and Industry 4.0, A/SS* and *warehouse automation.* To create an initial understanding of potential underlying issues before a more exhaustive literature review was conducted in phase 2 and the structure of the case study design as well as data collection methods were set, a pilot Gemba walk was carried out. This helped to narrow down the problem space and to only focus on the literature that was relevant during the second review, plan the interviews accordingly and gain ideas for what data to collect for further analysis. The packers that collaborated in the pilot study were asked to highlight which problems they experience in their daily work, which helped to gain an idea of what to look for when the second round of observations was to be performed.

3.5.2 Phase 2

The research questions were developed and refined in an iterative process. The understanding of processes that were attained during multiple visits to the warehouse along with the comprehensive literature study served the purpose of formulating the research questions to be answered. After conducting the pilot Gemba walk and gaining a better understanding of underlying issues, the final research questions were set.

From reviewing the available literature in the first round of study, some research gaps were identified. Namely, it was evident that previous researchers have been focusing on the picking process and that research on the packing process was considerably limited. Moreover, the literature available on Lean warehousing highlighted the conceivably high rewards of implementing Lean applications in a warehouse setting, but also emphasized the scarcity of research on this topic. Hence, one of the identified gaps was that Lean principles and especially VSM could be used in warehouses to a greater extent than what is the case as of today. The authors that developed the framework that will be applied in the study also articulated a need for implementing the framework in a case study to investigate its usefulness. This motivated the choice of research design and methodology.

The study will apply the three-step framework for Lean warehousing, presented by Mustafa et al. (2013) and further discussed by Cagliano et al. (2018). The framework uses multiple Lean tools, starting with the 5Ws for each of the eight warehouse wastes. As a second step of the framework, the 5S technique is used to design suggestions for improvements and control the waste activities that have been encountered. The 5S will be applied to each of the wastes identified in the first step of the framework. VSM constitutes the final and third step and will be used to understand the current state of packing operations. A future-state map will be drawn but no implementation plans for it will be developed as a part of the thesis. Before collecting any empirical data, the product family at focus for the VSM was determined. In the case study, the CO light packing division is in scope. It also happens to be that all spare parts in the CO light packing division have identical flows, and therefore these can be selected as a product family. However, since the product characteristics of goods characterized as BG and goods that are considered as non-bulky differ in some ways, although the flows are similar, two separate analysis have been made for these two during VSM.

3.5.3 Phase 3

As the preparatory work was completed, the next step was to collect empirical data. This phase of data collection corresponds to the first step in a Lean implementation process, see Figure 8, section 2.2.1. The phase involved observations, so-called Gemba walks, and interviews with personnel at different positions that could provide insights. The first observations and interviews took place during two days. During the same dates, the first time study was also carried out and the time taken to complete 116 orders, 58 orders during each of the dates, was measured. To provide a fair estimation for the average time of the packing process, samples were randomly chosen throughout the days. The time was measured for a variety of order sizes and at different packing stations, where different packers were working. At a later time, the packing process time for bulky goods was also included in this study. To estimate the time for the current state process of BG orders, 34 orders were timed. The time to pack an order was measured from the point where the packer chooses which order to pack next, to the point where the packer puts away the sealed package, either to a shipping pallet or a trolley. To quantify the waiting times in the interface between picking and packing, secondary data from the ERP system was also requested and analyzed.

The time that workers were working actively with packing the order was compared against the time that the order spends in the packing and consolidation area to evaluate the proportions of each. The time that workers were actively working with packing each order involved many of the warehouse wastes that were identified through the observations. Therefore, a second time study, including 146 orders, was conducted to estimate how much time of the packing process that is necessary for a potential future-state packing process, without the occurring waste. This was done by simulating a packing process where some of the different non-value-adding steps had been eliminated.

3.5.4 Phase 4

In the fourth and last phase, suggestions for improvements were devised. This phase corresponded to the second and third steps in a Lean implementation process; data were analyzed and based on the data analysis, changes for waste elimination were made to define a new packing process. The 5S tool was applied for all of the identified wastes, whereas the wastes that were linked to the layout was then investigated more closely. ERP data were analyzed to find solutions for a layout that could handle the volumes efficiently, while eliminating as much waste as possible.

The fourth and fifth phase of the Lean implementation process; making the change and measure the benefits, was not included as a part of the thesis.

3.6 Credibility of Research Findings

To assure the trustworthiness of the results, the credibility must be safeguarded as data is collected and processed for the purpose of the study. Based on its credibility, the data can be used and analyzed for the research purpose. To ensure the credibility of research, most attention has been paid to two important aspects: validity and reliability.

3.6.1 Validity

In line with Saunders et al. (2009), validity concerns the establishment of the correct measures for the concept at study. In other words, it considers whether the study measures what it was originally intended to measure.

3.6.2 Reliability

Reliability refers to the extent to which repeated procedures of data collection will yield consistent findings and conclusions (Saunders et al., 2009). The objective is to assure that if a later investigator would perform the same case study all over again, that investigator would arrive at the same conclusions (Yin, 2003). According to Saunders et al. (2009), reliability can be assessed by the three requirements of reliability. First, the study must yield the same results on other occasions. Second, similar observations should be obtained if another observer would make them. Third, it has to be clear how the researcher has arrived at the conclusions from the collected data. The objective of reliability is to assure that errors and biases in a study are minimized (Yin, 2003).

3.6.3 Validity and Reliability for this Case Study

Yin (2003) explains that by following three principles in the data collection process, validity and reliability of the case study evidence can be established. The first principle is that of triangulation, emphasizing the importance of using multiple sources of evidence. The various sources of evidence are complementary and any data collection efforts should preferably use multiple of them. The reliability of data will increase if multiple sources of data on the same phenomenon are used in the analysis (Voss et al., 2002). Yin (2003) further explains that the second principle concerns the way that the collected data is organized and documented. For the typical case study, notes are likely to be the most common data component. The notes must be kept in such a way that both the investigator and others can retrieve the information efficiently. The third and last principle is to maintain a chain of evidence. This is accomplished by allowing an external observer to follow how evidence has been derived, from the initial research questions to the final conclusions. The external observer should also be able to trace the logic in the other direction, from the final conclusions to the initial research questions.

By combining three different data collection methods in the form of direct observations, interviews and secondary data, the intentions are to achieve triangulation to strengthen the reliability. By taking notes from the interviews, the reliability of the study is enhanced as it is then possible to verify answers afterward. Only three interviews were carried out as a part of the data collection process, which is few compared to the majority of case studies. The reliability could be increased by asking the same set of questions to a greater number of respondents. As already mentioned, this would be time- consuming and three interviews are believed as sufficient since observations will be the primary collection method for waste identification. As such, the interviews are only used as a complementary data collection method and to identify waste that could not be observed during the observations. For the different time studies that are used for data collection, five days are dedicated to collect data on packing process time for different orders to be able to estimate an average time that is as accurate as possible under the existing time limitations, hence increasing the reliability of the data. To assure validity, the same procedures are used when timing each sample. The time measurements are also divided into a study of the time to pack regular orders and BG order separately, since their packing time and occurrences varies, which is why analyzing all orders altogether could distort the results. To capture order data variations, one month of ERP data is analyzed. This is to find the average volumes as well as to identify the peaks. A longer timespan could possibly have yielded different values, but as growth will also be considered, it is considered that one month of ERP data is sufficient to estimate the required capacity for the process and assure validity.

3.6.4 Generalizability

Saunders et al. (2009) define generalizability, sometimes referred to as external validity, as the extent to which the findings of a study can be equally applicable in other research settings, e.g. other organizations. This is especially important when a case study is conducted in a single organization and if that organization is markedly differing from others in some way. In such cases, the conclusions that can be derived from the research will not be generalizable to others, and the purpose will be to simply explain the particular research setting within the study.

This research is conducted as a single-case study. According to Voss et al. (2002), the advantage of using a single case for a study is a greater depth. However, it limits the generalizability of conclusions. By the use of multiple cases, the opposite would be attained, meaning less depth per case but an augmented external validity.

Chapter 4

The Current State

This chapter focuses on the first step of a Lean implementation process, previously described in Figure 8, section 2.2.1: Observe current processes and look for waste. The chapter identifies the current state of the warehouse by presenting the empirical findings of the study. Findings from interviews, VSM and data analysis of secondary data are summarized. The chapter is divided into three different sections. It begins by providing an overview of the outbound processes. The layout of the current packing area is described as well as the general activities in the current packing process. The identified warehouse wastes are then defined and classified. To quantify the wastes identified through observations, data from the case company's ERP system is analyzed and the results are summarized. Lastly, the current-state map is drawn.

4.1 Overview of Outbound Area and Processes

To understand how the material flow and layout are currently designed for the packing process, an overview of the outbound flows, the packing area and the general process of packing goods is provided. For the complete map of the warehouse layout, please refer to Appendix A. For clarification purposes, it should be mentioned that whenever referring to the WMS in the report, this is the same system as the ERP system Movex, that AL currently uses.

4.1.1 Outbound Layout and Processes

4.1.1.1 Picking Zones

The picking area is divided into eight zones, where different MHE are being used to pick from the different zones, including high-reach trucks, forklifts and picking carts. The H zone represents high picks, from higher racks and the L zone represents low picks from lower racks throughout the picking area of the warehouse. Six automatic shuttle systems, similar to paternoster systems, are in place in proximity to the packing area of the warehouse and represent six different zones, numbered E1-E6. The shuttles are used for buffering of smaller items, and represent about 15-20% of picks. DG are stored in a separate area but requires no special material handling in the picking process, as opposed to the packing and shipping process.

4.1.1.2 Picking Strategy

A strategy similar to the synchronized zone picking strategy is applied. The picker will decide which order lines to include in a batch, as this cannot be automated by the WMS. According to the SOP, a picker should not take out more than 40 order lines in a batch, but the number will vary with each batch. For the most part, decisions of which order lines to pick first are taken with regards to the order deadline to make sure that orders can be delivered on time.

One or multiple order lines that are included in the same customer order and are picked from the same zone will make up a "suffix". In the WMS system, each suffix is highlighted in different colors depending on the number of zones an order will be picked from and whether someone has started picking any of the other suffixes included in the customer order already or not. The suffix is also highlighted in green if it is the last suffix of an order that has not been batched yet. All of this is to make it easier for the pickers to take decisions on which order lines to pick next to decrease the time it takes to consolidate a customer order and meet shipping deadlines. However, the efficiency of the picking process is completely dependent on that the pickers follow the SOP.

4.1.2.3 Sortation and Consolidation

Order batches will be picked to the pallets that have pallet collars, which pickers will transport by truck. From zones E1-E6, suffixes are picked to picking carts. When a picker has picked all order lines in a batch, the picker will travel to the gravity flow racks that comprise the consolidation area. The pickers sort the articles according to customer order, as each lane in the flow rack will only contain a single customer order. This goes for all lanes except the ones that are marked "NC", meaning non-consolidation. In the consolidation area, each suffix is placed in a storage bin for further consolidation with other suffixes of the same order. The NC lanes contain multiple orders that have only been picked from one zone, hence only representing one suffix in the WMS. This means that any storage bin that is placed in any of the NC lanes is directly available for packing since the suffix is not waiting to be further consolidated with articles from other zones.

4.1.2.4 Packing and Shipping

The packing process is explained in more detail in section 4.1.3. As soon as the package has been placed on the shipping pallet, the responsibility of it is handed over to the dispatch function. Employees at dispatch will transport the pallets to the staging area and prepare each delivery for transportation to customers.

4.1.2 The Packing Area Layout

Figure 19 shows the layout of the current packing area. The automatic shuttles zones, E1-E6, are also displayed in the top-right corner. As some of the packing area's different sub-areas will be further discussed in the report, these have been highlighted in the figure. Digital photos of the packing area are also displayed in Figure 20-23. The layout of the entire warehouse, including the inbound, picking and shipping area and where the packing area is situated in relation to them, can be found in Appendix A.

The packing area has a total of nine packing stations, numbered from 5 to 13. The packers are free to choose which packing station they will be working in and each station can be operated by different employees during different days or even times during a single day. The number of employees dedicated to packing will vary throughout the day, depending on the current workload for the packing process. In general, the number of employees dedicated to packing will be about 3-4 in the mornings and close to using the full capacity with nine packing stations in the afternoons.

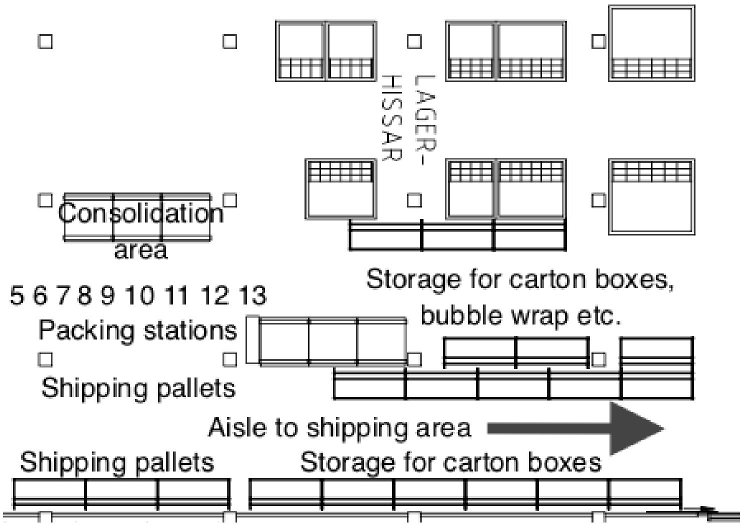

Figure 19: Layout of packing area

Packers stationed at packing stations 5 and 6 are responsible for packing bulky light goods. Due to the dimensions of BG, such orders are not consolidated in the gravity flow racks but on two separate shelves next to them, to the farthest left of the consolidation area, see Figure 19. However, when there are no BG orders to pack, the packers that are working at packing station 5 or 6 at the time will help their co-workers with packing of other orders in the meantime. Packing station 13 was originally intended to be used to pack DG but is generally not in use. However, this is where most of the labels that are needed to label DG packages are placed. Instead, DG can be packed at any work station by whoever has gone through the appropriate training to pack DG. The DG lane in the consolidation area is situated in the flow racks between packing stations 9 and 10.

Table 8 displays an estimate of the percentage which each order type represents. From Table 8 it can be concluded that a majority, about 55 percent, of orders are NC orders. The order size for NC orders is generally smaller compared to orders that require consolidation, although this does not always have to be the case. For NC orders, the average order size is approximately 1,7 order lines. The corresponding number for orders requiring consolidation is 5,5. Hence, NC orders represent more than half of customer orders, but only about a third of order lines. Similarly, BG orders also represent a lower number of order lines per order.

Table 8: Distribution of order classes

Order type	**# orders (%)**	**# order lines (%)**
NC orders	55	30
Consolidation orders	35	63
BG	10	7
DG	< 0,5	< 0,5

There are currently 13 types of boxes that are used for packing, but the frequency in which they are used varies. Five smaller carton boxes, of size T-03 to T-06, as well as the medium-sized boxes T-09 and T-13, are placed on shelves above and beneath each packing station. The remaining carton boxes are located across the aisle, see Figure 19 and Figure 23. Each packing station, see Figure 21, is also equipped with the following items: stitcher, staples, tape, knife, measuring tape, labels ("fragile", "mixed goods", "this way up" and "gasket inside"), bubble wrap, printer, plastic pockets, plastic bags, scanner, scale and protective paper. The labels used for the packing of DG can be found by packing station 13. A padded floor mat is also in place in front of every station, for ergonomic purposes. In proximity to packing stations 5 and 6 is a strapping machine located. It is mainly used when sealing heavier packages or packages containing BG. The storage area for bubble wrap and additional carton boxes are located next to the packing area, as highlighted in Figure 19 and shown in Figure 23. Shipping pallets are located on both sides of the aisle that leads to the shipping area, see Figure 23.

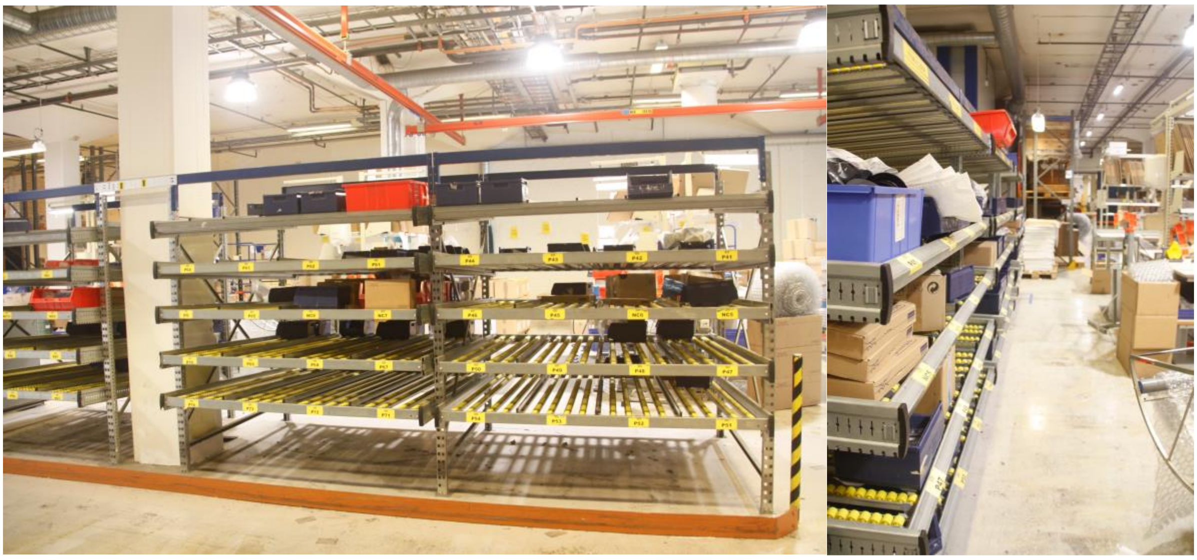

Figure 20: The consolidation area

Figure 21: Packing stations

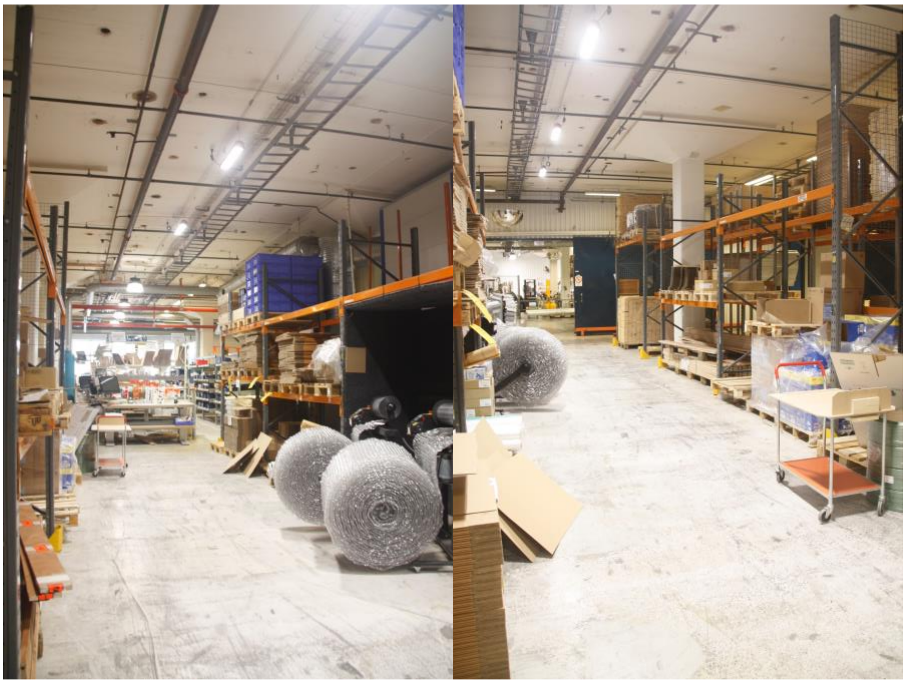

Figure 22: Storage area for carton boxes and bubble wrap

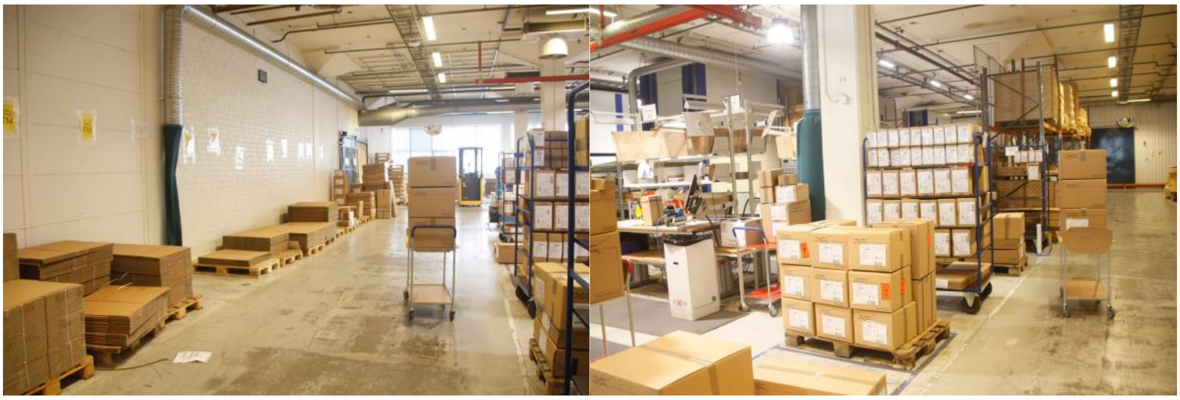

Figure 23: Aisle leading to the shipping area. The areas on both sides next to it are used for storage of carton boxes and shipping pallets

4.1.3 The Packing Process

The process of packing an order starts when the packer will look for customer orders in the WMS and decide which order to pack next. In the WMS, the orders are sorted according to the scheduled delivery time so that the earlier deliveries will be displayed and therefore, hopefully, packed first. When the packer has decided which order to pack next and checked in which lane in the gravity flow racks that it is placed, the packer walks over to the racks to collect it. The order can be lying in one or multiple storage bins, depending on the number of suffixes that make up the order and the size of the items. The packer takes the storage bin, or bins, to the packing station. It is not until then that the packer can start to pack the order.

The choice of a suitable carton box that each order can be packed in is based on the packer's experience, in such a way that the extra work of having to reallocate items between cartons can be avoided. Sometimes, measuring tape is used to help determine a suitable choice of carton. Depending on the carton that is chosen and its storage location, the packer either needs to walk across the aisle, seen in Figure 23, to collect it, or fetch it from the top or lower shelves by the packing station. The bottom of the carton is stapled and taped, before the carton is placed on the workbench. Each article of the customer order is scanned. The packer checks that the article number corresponds to the one in the WMS and whenever an article contains less than 20 items, each item is counted to make sure that the correct quantity has been picked. The quantity is noted in the WMS. Every prepackaged article must be jolted to make sure that it will not be damaged during transportation. As each article is scanned, it is placed in the carton box. Every article in the customer order, as well as protection material, is put in place in the carton. Bubble wrap is used in a vast majority of packages, but other forms of protection material are also being used. When the packer has assured that the items will be protected from potential damages during transportation, the carton box is sealed, stapled and taped. The package is weighted on the scale. The choice of carton box and the resulting weight are registered in the WMS. The packer verifies that the net weight corresponds to the accumulated net weights of the articles in the order, and is within an acceptable margin of error. This is to assure that the correct products have been picked and packed. When the packer reports to the WMS that the order has been packed, the consignment-note, customs invoice and shipping label are printed. They are both folded and put in a plastic pocket that is affixed to the package.

Lastly, the package is placed on a shipping pallet according to the transportation carrier that is responsible for the delivery of the order. This is sometimes done by the packer directly, as the packer will walk over to the transport carrier's pallet before proceeding to pack the next order. In some cases, the package is initially placed on a trolley, such as the ones that can be seen in Figure 21-23, together with other packages. Since the packages that are put on the trolleys are often going to be transported by different carriers, this adds a further sortation process where each package is transported and sorted to its designated transportation carrier's pallet as the trolley reach its storage capacity limit.

Sometime during the process of packing an order, the packer will take the empty storage bin, or bins, and put them back onto the top rack of the flow racks that are sloping towards the pickers' side of the racks. Either this is done when the packer is on its way to collect the next order do pack, or earlier while the packer is still working on packing the order.

4.2 Waste Identification

Observations of the packing process are conducted to identify waste and questions are sometimes asked for clarification purposes. Moreover, interviews are conducted to reveal aspects that might be more difficult to identify through observations or that could not be observed during the days when observations are organized. To quantify the occurring waste, the results from a conducted time study and analysis of ERP data are concluded.

4.2.1 Waste Classification

The wastes that can be identified are guided by the waste classification framework from the research of Jones (1995). Through observations and interviews, a total of 40 wastes are identified. These are all classified and explained in Table 9 and Table 10.

Table 9: Waste classification from observations

WASTE TYPE	IDENTIFIED WASTE
1. Traveling	1. Traveling to the consolidation area to collect an order to pack 2. Traveling across multiple packing stations to collect an order to pack 3. Traveling across the aisle to collect a suitable carton box 4. Traveling within the packing area or across the aisle to place a package 5. Traveling within the packing area to find a trolley to place the package onto 6. Traveling to refill carton boxes and bubble wrap at the packing station 7. Traveling to the consolidation area to return empty storage bins 8. Traveling to the DG lane to collect orders to pack and to collect DG labels at work station 13
2. Inventory	1. Consolidation area stores orders waiting to be consolidated 2. Consolidation area stores completed orders waiting to be packed 3. Packages stored onto trolleys for further transport to shipping pallets
3. Over processing	1. Manually determining which order to pack next 2. Gathering multiple storage bins to collect an order instead of one 3. Moving around the storage bins, sorting and consolidating the articles into one or fewer storage bins for orders that are yet not fully consolidated 4. Scanning each article twice 5. Excessive consignment-notes are printed for DHL and need to be discarded 6. Excessive bubble wrap is needed to fill the box and assure protection as the box that was chosen to pack in is too big 7. Searching for a NC-order that has an earlier departure time than the NC-orders placed in front of it 8. Having to clear out the path from trolleys 9. Printing custom invoices through a separate system for some orders 10. Stapling cartons of smaller sizes, e.g. T-04 and T-05
4. Waiting	1. Waiting for consignment-notes and shipping labels to be printed
5. Unnecessary motion	1. Preparing and packing goods directly on the floor 2. Carrying relatively heavy packages across the aisle
6. Correction of mistakes	1. Weights for different articles have been incorrectly noted in the system and requires to be updated 2. Incorrect quantity picked 3. Incorrect article picked 4. Re-packing articles that have not been packed in appropriate containers by suppliers for better protection 5. Preparing and trying to pack an order in a carton box of the wrong measurements and having to repack the order 6. Misplaced storage bin containing an article in the wrong lane, where a different customer order is being consolidated

7. Metal products weighing over 17,5 kilos that are picked to the light packing area
8. Missing to place one or several articles in the package before sealing it
9. Storage bins that are not collected as they are stuck further back in the gravity flow racks, not visible to the packers

Table 10: Uncovered problems from interviewing packer staff

WASTE TYPE	IDENTIFIED WASTE
3. Over processing	11. Prolonged time for counting each item of an article and performing quality assurance as each item needs to be taken out of the plastic bag to be counted 12. Putting one of the consignment-notes in the package and one in the plastic folder 13. Unnecessary double handling since SOP is not always followed, as some packers take out every article from the storage bins and spread them across the workbench, before scanning and putting them into the carton box
4. Waiting	2. Printer not working due to system failure
5. Unnecessary motion	3. Ergonomic issues at packing station 5 and 6, where BG are packed 4. Almost running into other workers at the packing station
6. Correction of mistakes	10. Increased number of human errors as a result of stress

4.2.2 The Order Packing Time in the Current-State

The existence of waste in the packing process will ultimately increase the time to pack an order. To estimate the time it takes to complete the process of packing a customer order with the occurring waste, a time study is performed. The time measured from packing 116 orders, by seven different packers, forms the basis for the results that are displayed in the figures and tables in this section, along with secondary data from DC Tumba's ERP system. Since BG often requires additional handling in the packing process, 34 orders of BG, packed by two packers, are timed and then analyzed separately.

4.2.2.1 Overview of Data Set

Not surprisingly, the averages of the individual data points from Figure 24, displayed in Figure 25, show that orders with a high number of order lines take longer time to pack. The results also show that the average packing time per order line decrease with an increasing order size. From observations, it is concluded that this is mainly due to the longer time of scanning and counting that the correct quantity of each item has been picked, whereas the time to collect articles from the consolidation area and find the appropriate carton box, prepare the package, seal the package, print shipping labels and consignment-notes and finally put-away the package on a pallet or trolley is similar regardless of the order size.

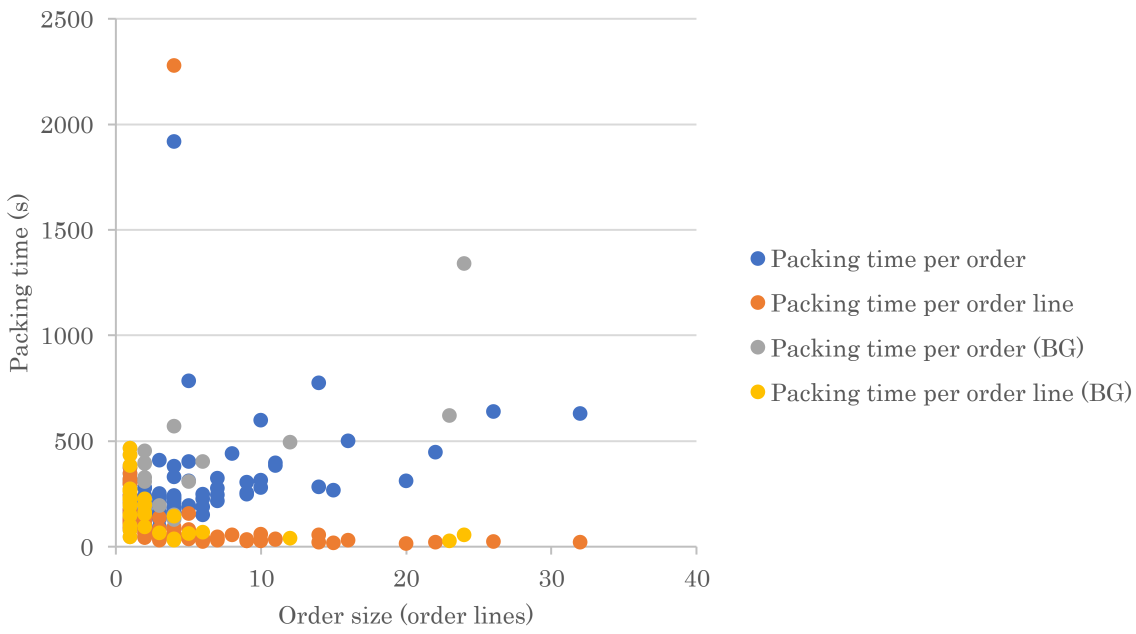

Figure 24: Overview of complete data set from the performed time study of the current process

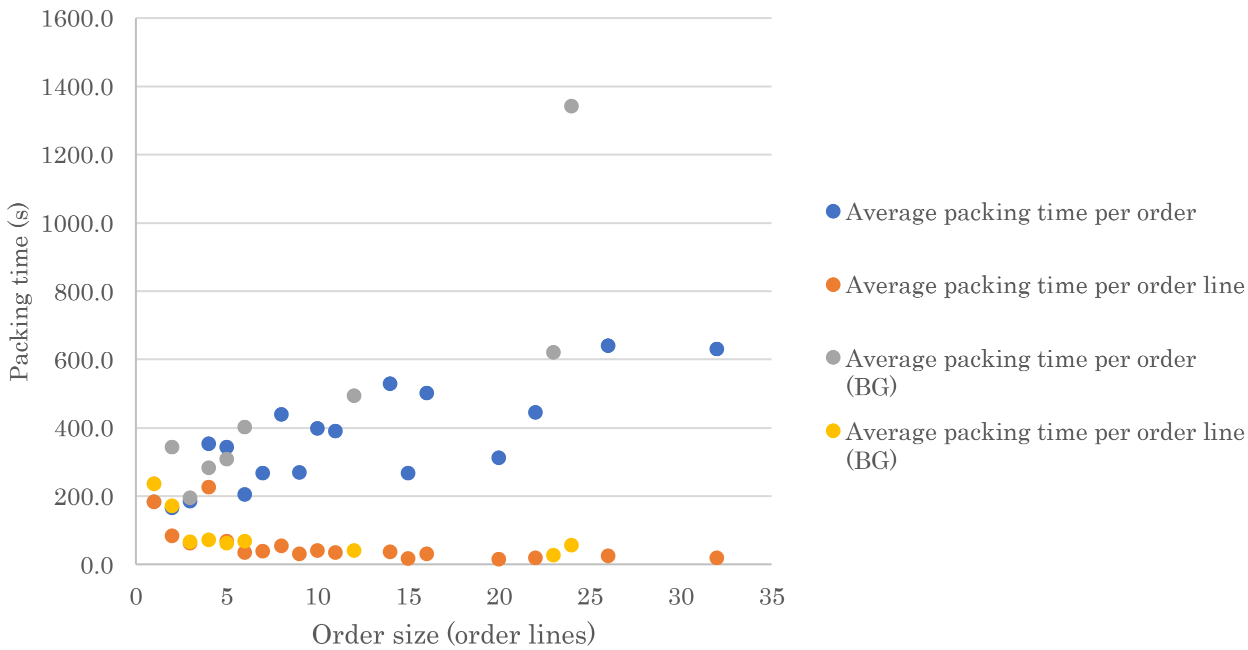

Figure 25: Average packing time per order and order line in the current process

4.2.2.2 Factors Affecting the Packing Time

A significant share of the products that AL DC Tumba handles is characterized by their fragility, resulting in a high need for protection from damages during transportation. However, this can differ depending on which articles that are included in each customer order, which will ultimately lead to a significant variation in the packing process time for different orders. Naturally, the more articles that make up a customer order, the more likely it is that any of the included products needs repackaging, additional protection or that other additional, and time-consuming, steps are required. But since such additional steps highly differ depending on the products that an order contains, the time to pack orders of the same order size varies a lot, as can be interpreted from Figure 24. From the same figure, it can also be concluded that packing BG is more time consuming, usually due to the higher need for special handling and protection material for packing.

4.2.2.3 Data Validation

Table 11: Order data for the light packing area from the two days at study

DATE	2019-05-27	2019-05-28
# timed orders	58	58
# packed orders	480	467
# packed order lines	1375	1317

As mentioned, data from two dates, 2019-05-27 and 2019-05-28, forms the basis for the time study for the current-state. During these two dates, a total of 947 orders are packed in the light packing area, but only 116 orders of them could be timed. Since it is concluded that there is a great variation in packing time and that the packing time is highly dependent upon the order size, data from the ERP system is extracted to validate how representative the samples are for the orders that are packed during the particular days that are being studied. When the data set has been validated, the data can be extrapolated to calculate an estimate of how much time packers are actively working with an order throughout the day. To do so, the order sizes are grouped into three different categories: orders containing 1-4 order lines, 4-9 order lines and orders exceeding 9 order lines.

Figure 26 proves that there are great similarities between orders size distribution of the orders that are packed during the two consecutive days when the time study takes place. The two data sets can therefore be treated as a single data set, and do not require to be analyzed individually from now on. Furthermore, Figure 27 shows that the order size distribution for the data set that is randomly being selected reflects the order sizes of all orders registered for packing in the ERP system during the same dates and assures that orders of various order sizes are being studied. During the time study, 72 percent of samples are from orders of order size 1-4 order lines. It would have been desirable to have a greater sample number for the two other order size categories, but, as Figure 27 demonstrates, these orders represent less than 15 percent of the total number of customer orders. This naturally resulted in that they are timed less frequently as the study is carried out. The fact that two of the categories represents less than 15 percent of orders means that a margin of error in the average time to pack any of the larger order sizes will not have a significant effect on the final estimate of the total order packing time, since this is mainly made up of the time dedicated to packing orders of the order size 1-4 order lines. Thus, it is more important to have a greater sample number for the order size 1-4 order lines since the accumulated time of packing these orders will have a greater effect on the outcome.

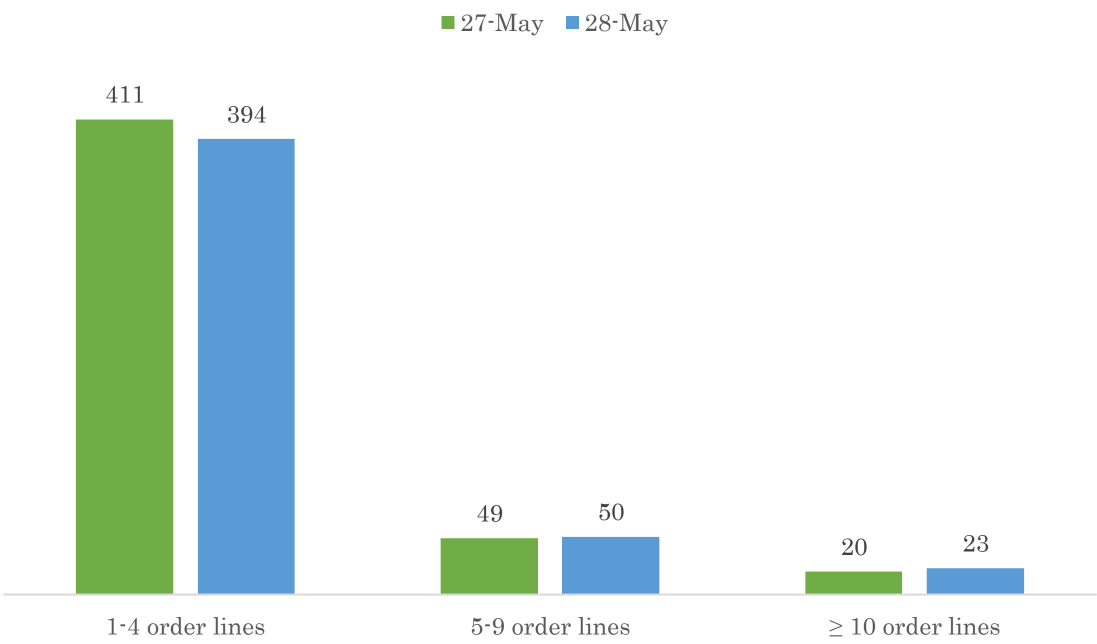

Figure 26: Distribution of order sizes

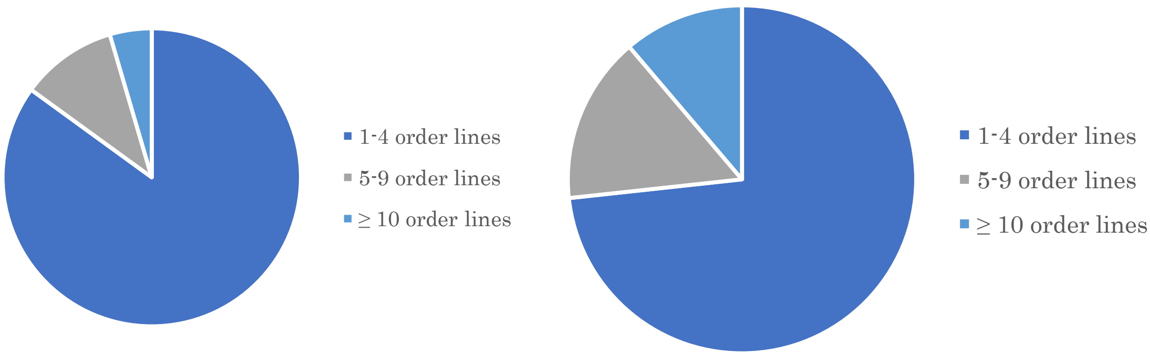

Figure 27: The left pie chart displays the distribution of order sizes concluded from ERP data and the right pie chart shows the corresponding distribution for the collected data set for 2019-05-27 and 2019-05-28

4.2.2.4 Average Packing Time per Order and Order Line

Figure 28 shows the average packing process time per order and order line for the three different order size categories. The results for orders of size 1-4 order lines are based on 85 samples. The corresponding number for orders of size 4-9 order lines and of 10 order lines and above is 18 and 13 samples. The average order packing time across all samples, BG orders excluded, is 5,13 minutes.

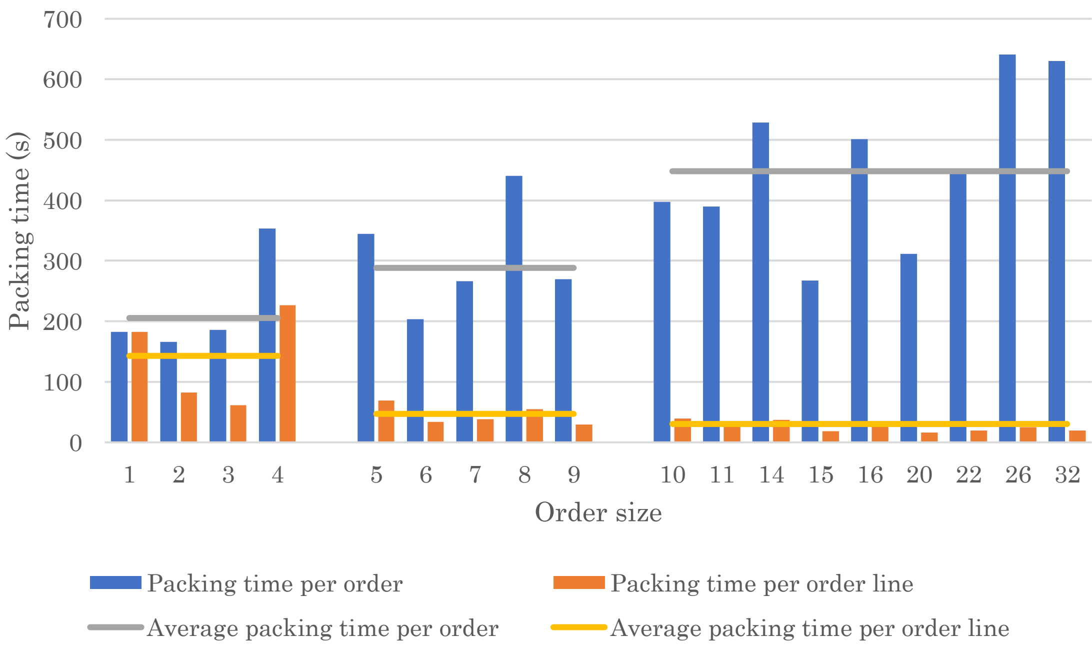

Figure 28: Packing Time Per Order Line for the three order size categories, BG excluded

4.2.2.5 Estimated Total Time For Order Packing

The tables numbered 12 and 13 show the number of orders and order lines that are packed during the two days at study. The result from section 4.2.2.4 for the average packing time per order line is used to compute the total packing time, which is summarized for each order size category.

The packing time per order line from Figure 28, section 4.2.2.4, excludes all BG orders. As a part of the time study, a separate study is performed to gain an idea of how much longer time that is required to pack a bulky order of any size at packing station 5 or 6 compared to a regular one. This study involved 34 orders, packed by three different packers. Based on the average packing time per order line, results show that it takes 53,9 percent longer time to pack an order line in a BG order of any size. Since it is not evident from the ERP data which orders that are bulky and which are not, this number is then used to extrapolate the estimated packing time for the regular orders to compensate for the additional time that these orders require as the total time is being summed up, see Table 12 and Table 13.

Table 12: Estimated total time for order packing during 2019-05-27

Order size	Average packing time/ order line	Number of orders/ category	Number of order lines/ category	Total time
1-4 order lines	143 s	411	654	25h:58m:42s
5-9 order lines	47 s	49	342	04h:27m:54s
≥10 order lines	30 s	20	379	03h:09m:30s
		∑ = 480	∑ = 1375	∑ = 33h:36m:06s
BG extrapolation			33h:36m:06s * 7% * 0,539 = 01h:16m:05s	
Total sum			∑ = 33h:36m:06s + 01h:16m:05s = 34h:52m:11s	

Table 13: Estimated total time for order packing during 2019-05-28

Order size	Average packing time/ order line	Average number of orders/ category	Average number of order lines/ category	Total time
1-4 order lines	143 s	394	673	26h:43m:59s
5-9 order lines	47 s	50	333	04h:20m:51s
≥10 order lines	30 s	32	311	02h:35m:30s
		∑ = 467	∑ = 1317	∑ = 33h:40m:20s
BG extrapolation				33h:40m:20s * 7% * 0,539 = 01h:16m:15s
Total sum				∑ = 33h:40m:20s + 01h:16m:15s = 34h:56m:35s

The results from Table 12 and Table 13, 34h:52m:11s and 34h:56m:35s, must then be compared to the number of workers and their respective working hours for the applicable days, see Table 14. The results show that there is a loss of about 30-40 percent of operating hours, which would imply that there is either more waste that is built in the processes that are not identified, or that the utilization rate is considerably low.

Table 14: Order packing time as a ratio of total working time

Date	Total packing time	Working hours	Packing time ratio (%)
2019-05-27	34h:52m:11s	Approx. 50h	70
2019-05-28	34h:56m:35s	Approx. 56,5h	62

4.2.2.6 Average Total Packing Time

To achieve a better estimate of the average number of orders and order lines being packed in the light packing area and the time it takes, data from multiple days need to be studied. As the DC does not experience any seasonality, the complete order history from May is viewed as being sufficient to capture demand variations. During the time period from 2019-05-02 to 2019-05-29, 8.151 customer orders, or 27.813 order lines, have been packed. The average number or order lines packed in the light packing area per day is 1.391. The average number of order lines and the variations in volume are illustrated in Figure 29. The average total packing time per day is calculated and displayed in Table 15.

Table 15: Average total packing time per day in the current-state

Order size	Average packing time/ order line	Average number of orders/ category	Average number of order lines/ category	Total time
1-4 order lines	143 s	323	543	21h:34m:09s
5-9 order lines	47 s	46	361	04h:42m:47s
≥10 order lines	30 s	29	487	04h:03m:30s
		∑ = 408	∑ = 1391	∑ = 30h:20m:26s
BG extrapolation				30h:20m:26s * 7% * 0,539 = 01h:08m:42s
Total sum				∑ = 30h:20m:26s + 01h:08m:42s = 31h:29m:08s

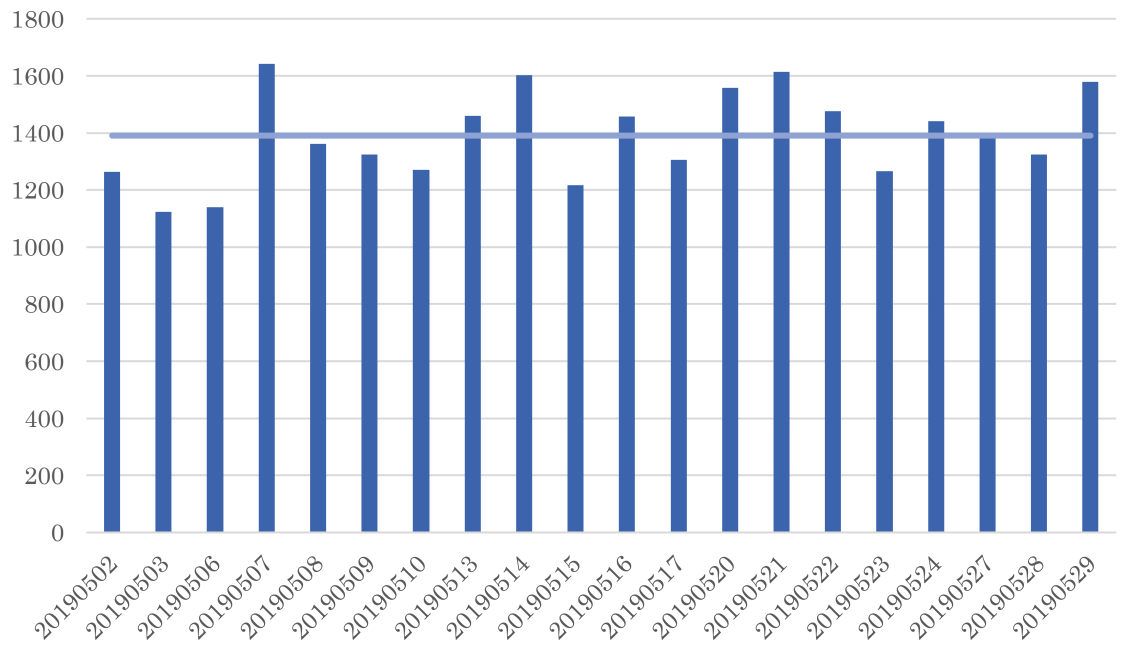

Figure 29: Number of order lines packed per day in May 2019

From Figure 29 it can be concluded that during both 2019-05-27 and 2019-05-28 the number of order lines registered for packing is close to the average. However, the order size distribution is somewhat different, as there is a higher proportion of the smaller order sizes compared to the average order size distribution. This should be noted as the order size distribution will have a significant impact on the packing time. During 2019-05-28, the number of order lines is below average. Yet, the high number of orders of small order sizes results in a higher total packing time, approximately 3,5 hours higher compared to the estimated average.

4.2.3 Waiting Time in the Consolidation Area

It has been concluded that two of the identified wastes, wastes 2.1 and 2.2, take place in the form of inventory in the consolidation area. Waste 2.1 is mainly dependent on the design of the picking process, which was explained in section 4.1.1.2. On the contrary, waste 2.2 is highly dependent on the design of the packing process. To quantify the severity of waste 2.2, ERP data on timestamps is requested and analyzed. The waste is quantified in terms of for how long a consolidated order that is available for packing is waiting in the consolidation area before actually being packed by any of the employees in the packing team.

4.2.3.1 Average Waiting Time in Consolidation Area

The result from data analysis, seen in Figure 30, shows that the average time that any order spends in the consolidation area even though it is ready for packing is 01h:03m:22s. The number is computed by subcontracting the average packing time across all order sizes, which is 5,13 minutes, from the average time difference in between the timestamps for when the order is consolidated and when delivery has been registered as packed, for all single order deliveries in May. Moreover, as displayed in Figure 30, some orders lie in the consolidation area for as long as 8,5 hours before someone packs it.

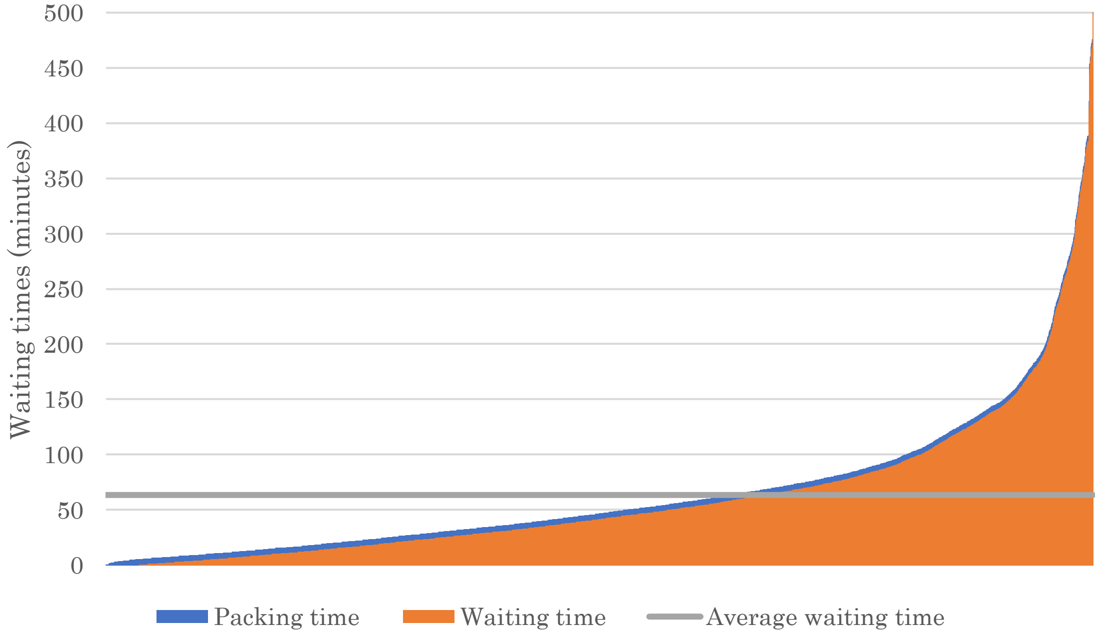

Figure 30: The ratio between actual packing time and the waiting time in the consolidation area for 6.834 orders during May 2019

4.2.4 Traveling for Carton Boxes

Waste 1.3 is identified through observations. Moreover, the waste can be quantified by looking at the use of carton boxes in combination with their known locations in the packing area. Figure 31 shows the frequency of which each carton type is used. The data shows that T-03, T-05 and T-09 are the most frequently used carton boxes. Data also shows that in 23 percent of the time, packers will for certain engage in unnecessary traveling to collect a single carton box. This occurs whenever packing in any of either carton types: T-11, T14, T-15, T-16, T-18, T-20 or T-21. The packing stations for BG seem to be responsible for a high share of the use of these carton types as these all represent the larger box sizes that are usually required for packing of BG.

The time to walk back and forth to collect a carton box on the other side of the aisle is estimated to take 15 seconds from observations. If this follows for 23 percent of the orders, this means that unnecessary traveling for carton boxes accounts for a waste of 23 minutes per day (23%*408*15s), based on average order data. This number indicates what time savings that could be realized by more appropriate placement of carton boxes.

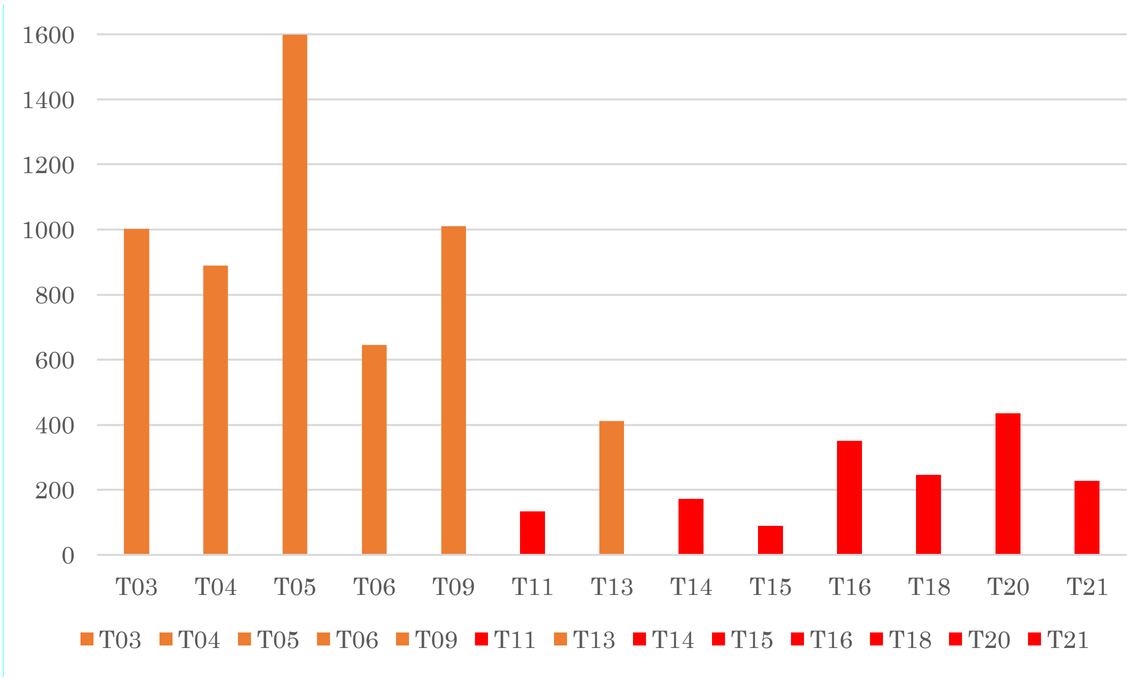

Figure 31: Frequency of use for carton boxes during May 2019

4.3 The Current-State Map of the Packing Process

After data has been collected, the current-state of the packing process can be mapped. Since the choice of WMS/ERP system is excluded from the scope, the information flows will not be included in the map. Moreover, as the mapping is done for an individual process and not on a higher process level, it does not include many of the icons in which a current-state map is usually illustrated by. Due to the many activities within the packing process, no time estimations for each of the steps are clocked during the current-state mapping. Instead, the average waiting time that was computed and presented in section 4.2.3.1 and the average packing time that was estimated in section 4.2.2 are together used to visualize the waste in the current process. The required number of operators can be translated to seven full-time operators, based on the result from Table 15, section 4.2.2.6.

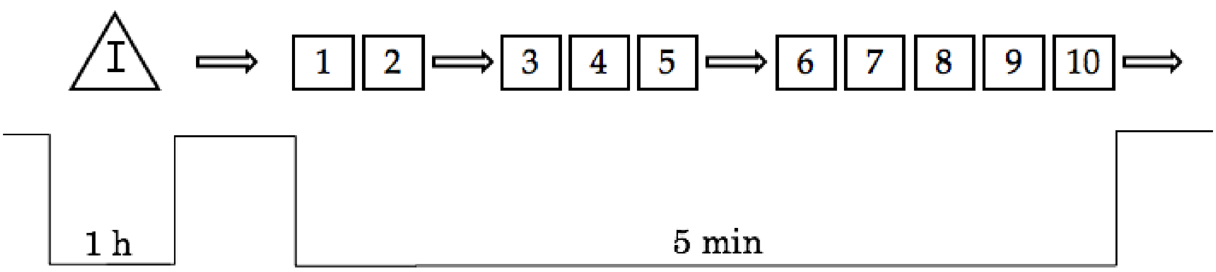

Figure 32: Current-state map of packing process

Table 16: Activities in the current packing process

STEP		CATEGORY
1	Decide which order to pack next	NVA
2	Travel to the consolidation area to collect order	NVA

3	Select and travel to collect suitable carton box	NVA
4	Staple and tape bottom of carton	NNVA
5	Scan articles and place in carton	NNVA
6	Add protection material and labels	NNVA
7	Weigh package	NNVA
8	Print and affix shipping label	NNVA
9	Seal carton	NNVA
10	Travel to put away package at shipping pallet	NVA

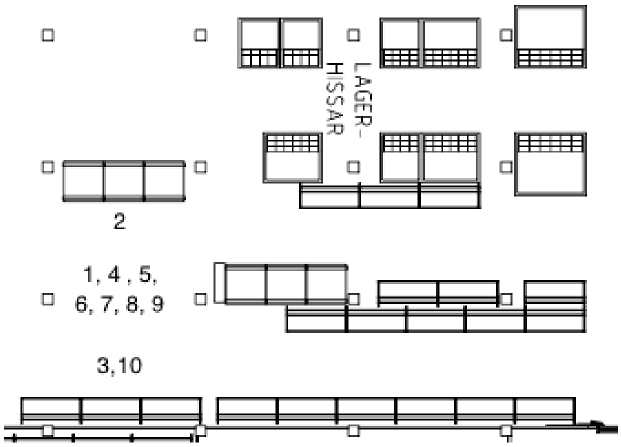

Figure 33: Map of where each of the steps takes place

Packing is a necessary activity that is being carried out to assure that the products reach the customer without receiving any damages. Nonetheless, packaging is not adding any value to the customer. As opposed to the MO packing area, where value is added through order kitting, there is no value added by the light packing area at AL DC Tumba. Table 16 shows which steps of the packing process, mapped in Figure 32 and Figure 33, that can be categorized as either NVA or NNVA.

Chapter 5

Waste Analysis

This chapter focuses on the second step of a Lean implementation process, previously described in Figure 8, section 2.2.1: Start to diagnose issues through data analysis. This is accomplished by using the proposed framework for Lean warehousing. All sections aim to answer one or both of the research questions respectively. Section 5.1 aims at answering RQ1. The two remaining sections are intended to serve as a first step in finding the answer to RQ2.

5.1 5Ws

This section aims to answer RQ1: Where in the packing process does waste occur and what are the root causes? This is accomplished by applying the 5Ws tool.

The complete table from the use of the 5Ws tool is presented in Table A1, Appendix C, section C.1. A summary of the main findings from applying the tool is presented in Table 17. The findings are presented as to how the current layout of the packing area is either directly or indirectly causing some of the identified wastes in the packing process, presented in Table 9 and Table 10, section 4.2.1. Some of the identified wastes are not linked to the layout of the packing area and will hence not be further addressed in the thesis as they are not a part of the scope. The wastes that are in fact linked to the packing area layout, and as such included in the scope, are mapped to either one or multiple causes.

Table 17: Mapping of how the current layout causes waste

WHAT	***WHY***
1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 2.2, 2.3, 3.1, 3.8, 5.2, 5.4	A man-to-goods system is being used and increasing the need for travel
2.2, 3.1, 3.7	The layout does not provide a visual workflow
2.2, 3.1, 3.2, 3.3, 6.9	The consolidation area and system are inappropriately designed
5.1, 5.3	The packing station design causes poor ergonomics when packing bulkier customer orders and orders of larger sizes

The analysis shows that the main issues in the current design of the layout are (1) the choice of applying a man-to-goods system, (2) a workflow that lack visibility, (3) an inappropriately designed consolidation area and system and (4) packing stations that are not designed for improved ergonomics during the process of packing of all order types, including BG and orders of larger sizes. Every waste in the traveling category is mapped to the first cause. Moreover, a man-to-goods system also causes waste by indirectly causing inventory and over processing. It also causes unnecessary motion as heavy packages must be carried and travel for longer distances. Besides being a result of the current man-to-goods system, waste 2.2 and 3.1 are also caused by the poor workflow visibility and design of the consolidation area. The poor design of the consolidation area results in an increase in inventory, over processing due to the double handling of storage bins, and can also lead to waste as a result of an increase in corrections of mistakes. Lastly, the packing station design causes unnecessary motion, because of poor ergonomics.

In addition to the wastes mapped in Table 17, waste 6.10 has not been included as it is a result of the other wastes that have been identified, ultimately resulting in a longer packing process time. If waste can be eliminated to reduce the packing process time, the workload would decrease, and along with it the number of human errors caused by stress.

5.2 5S

This section aims to answer RQ2: How can the packing process be redesigned for waste elimination by implementing warehouse automation and a new packing area layout? This is accomplished by applying the 5S tool.

The complete table from the use of the 5S tool is presented in Table A2, Appendix C, section C.2. A summary of the main findings from applying the tool is presented in Table 18. The findings are presented as to how the current layout of the packing area can be redesigned to eliminate the identified wastes in the packing process, presented in Table 9 and Table 10, section 4.2.1. Some of the identified wastes are not linked to the layout of the packing area and will hence not be further addressed in the thesis as they are not a part of the scope. For all wastes that are linked to the packing area layout, and as such included in the scope, suggestions for waste elimination are devised.

Table 18: Suggestions for waste elimination

WASTE	***SORT***	***SET***
1.1, 1.4, 1.5, 3.8	Eliminate unnecessary traveling and movement	Implement a goods-to-man system, using conveyors
1.2		Streamline flows by assigning one packer the responsibility for one lane
1.3		Place carton boxes according to FOM
1.6		Place storage of carton boxes and bubble wrap in a more convenient location
1.7		Install a reverse conveyor system that returns storage bins from packing stations back to the consolidation area
1.8		Assign responsibility of DG to a station that includes all necessary items used for packing of DG
5.2		Eliminate both traveling and the carrying of heavy packages by using outbound conveyors for packaged goods
5.4		Reduce the need for walking around the packing stations by using conveyors
2.2, 3.7	Eliminate inventory	Eliminate inventory by using a goods-to-man system and not relying on manual decisions
2.3		Eliminate the use of trolleys by replacing them with conveyors

3.2, 3.3	Reduce the number of storage bins in the system	Consolidate orders in fewer storage bins
3.1	Eliminate non-value adding steps	Implement a goods-to-man system, where packers do not take own decisions on which order to pack next
5.1, 5.3	Improve packing station design for the packing stations for BG	Design work stations so that all types of orders can be packed directly on the workbench by installing separate tables where more bulkier goods and/or orders of larger sizes can fit
6.9	Improve visibility in the consolidation area	Create improved visibility in the consolidation area by installing shorter racks or shelves for consolidation

The analysis shows that by implementing a goods-to-man system, using conveyors, several of the identified wastes would he reduced or eliminated. This would address waste 1.1, 1.2, 1.4, 1.5, 1.7, 2.2, 2.3, 3.1, 3.7, 3.8, 5.2, and 5.4. The placement of cartons should be overlooked, and packing stations that are suitable for packing larger and bulkier orders should be considered. The consolidation area should be replaced and new types of storage bins should be used for consolidation. By making such changes and eliminating wastes as suggested in Table 18, waste 6.10 can also be eliminated.

5.3 Proposal for a Future-State Map

This section aims to answer RQ2: How can the packing process be redesigned for waste elimination by implementing warehouse automation and a new packing area layout?

One of the pitfalls that Gooley (2010) identified, presented in the Theoretical Framework, was staying with manual processes when automation makes sense. In deciding to automate a process, volume and speed requirements should be reviewed. Moreover, the complexity of products will affect whether it is suitable to automate a process or not. Kembro & Norrman (2019) concluded that a high variety of product characteristics would also make it more difficult to take leverage of automation solutions. Due to the fragility of items, and the variety of product dimensions, it is assumed that complete automation of the material handling of products will not be feasible. A partial-automation strategy that could be integrated with the existing WMS, for example by installing a conveyor in a key area, is chosen as it will be less costly to implement and provide more flexibility.

According to Gooley (2010), companies with a large product portfolio could take advantage of machines that weigh and measure items to then select an appropriate box for shipping. The weighing of packages, step #5, could also be automated by the use of a checkweigher but since it is unclear how dependent this feature is on the WMS system, it is not further investigated as a part of the thesis.

The developed future-state map is illustrated in Figure 34 and Table 19. Three of the NVA activities included in the current-state map have been removed. Step #7 could also be eliminated by installing a tape-machine. This means that by implementing the future-state map, the steps of the process would decrease from ten steps to seven or six steps. The elimination of NVA activities is also reflected in a decrease in the average packing process time, see section 4.2.2.6. How the new average process time is determined will be explained in the next sections.

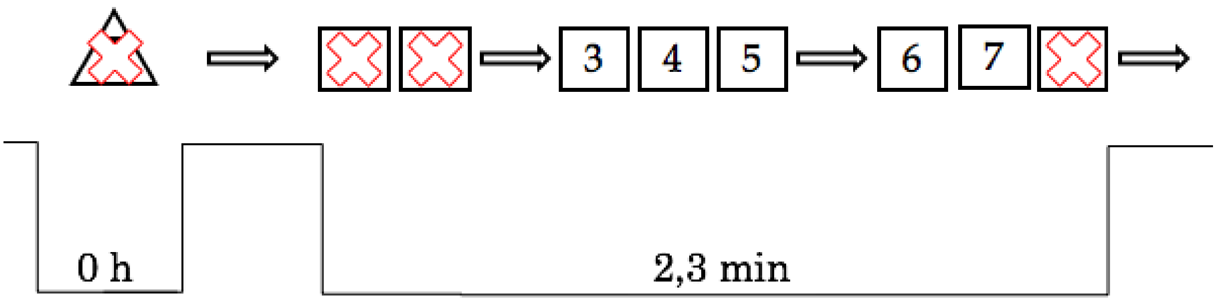

Figure 34: Future-state map for the packing process

Table 19: The activities included in the future-state process

STEP		CATEGORY
1	Select and collect suitable carton box	NVA
2	Staple and tape bottom of carton	NVA
3	Scan articles and place in carton	NNVA
4	Add protection material and labels	NNVA
5	Weigh package	NNVA
6	Print and affix shipping label	NNVA
(7)	Seal carton	NVA

5.3.1 Estimated Order Packing Time for the Future-State

To compare the time of the current packing process to the corresponding time in a suggested future-state packing process, a second time study is performed. A comparison of the result from both time studies can then be made. The packing times can respectively be translated into the required working hours for order packing and a cost-benefit analysis of the proposal of a new layout for the packing area can in this way show the potential gains of such an investment.

Since the future-state is not more than a proposal of a solution that is yet to be physically implemented, a simulation of the material flows in such a system is the only way of estimating what the new process time would possibly be. The new packing process time is established by timing a packing process where some of the identified NVA activities from the waste analysis are eliminated. From the current-state map, step #1, #2, #3 and #10 are neglected as orders are being timed. The study included 106 orders, packed by three different packers. In addition to this, 40 orders of BG, packed by three different packers, are timed and analyzed separately. The time for sealing and taping of carton boxes are also estimated.

5.3.1.1 Overview of Data Set

Figure 35 and Figure 36 show the results of the time study for the future-state packing process. The estimated average packing time per order and order line can be compared to the corresponding results for the current-state process, presented in Figure 24 and Figure 25, section 4.2.2.1.

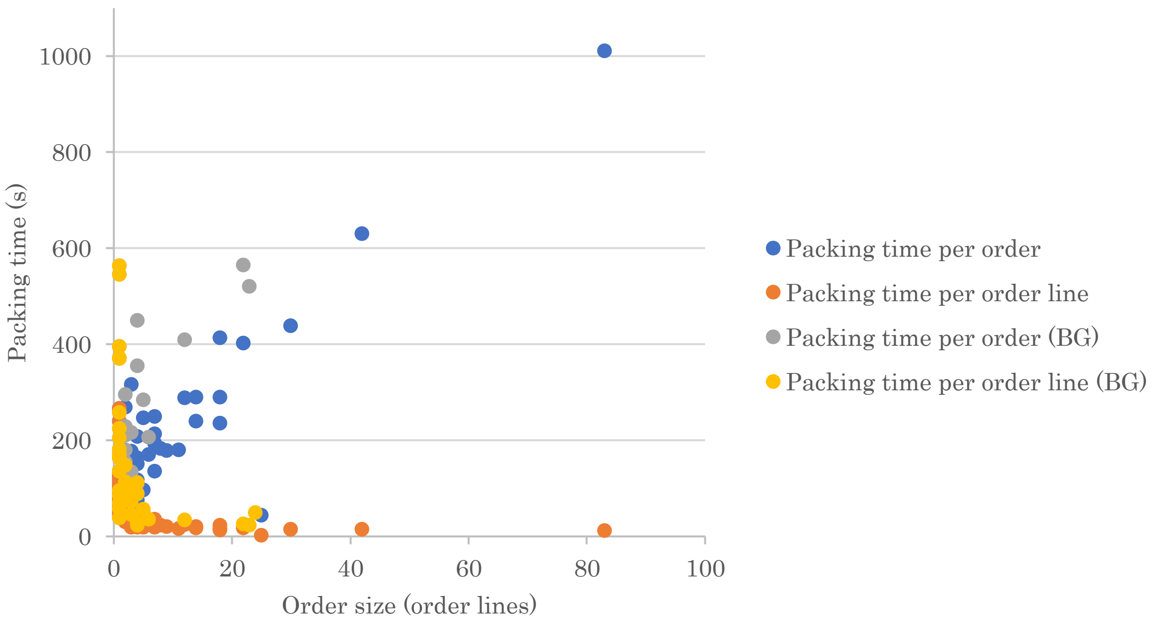

Figure 35: Overview of complete data set from the second time study for the future-state process

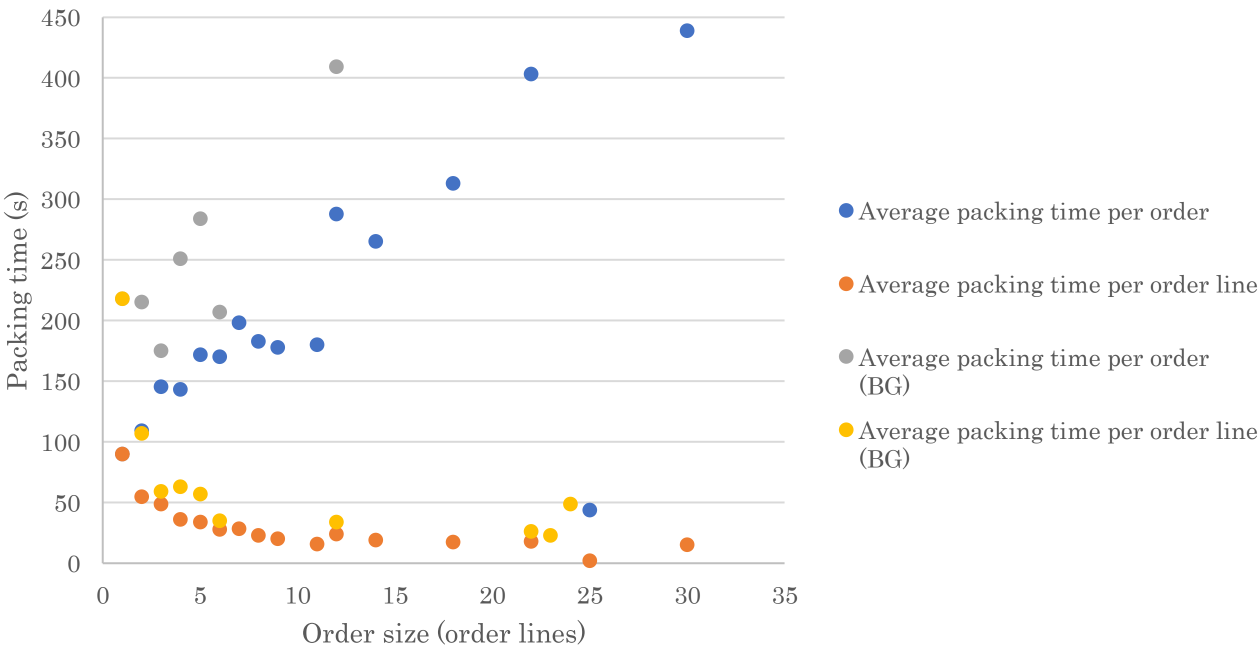

Figure 36: Average packing time per order and order line for the future-state process

5.3.1.2 Packing Time per Order and Order Line in the Future-state Process

Figure 37 shows the average packing time per order and order line for the three different order size categories from the second time study, excluding the time study for BG orders. The results for orders of size 1-4 order lines are based on 85 samples. The corresponding number for orders of size 4-9 order lines and of 10 order lines and above is 9 and 12 samples. The average order packing time across all samples, BG orders excluded, is 2,3 minutes.

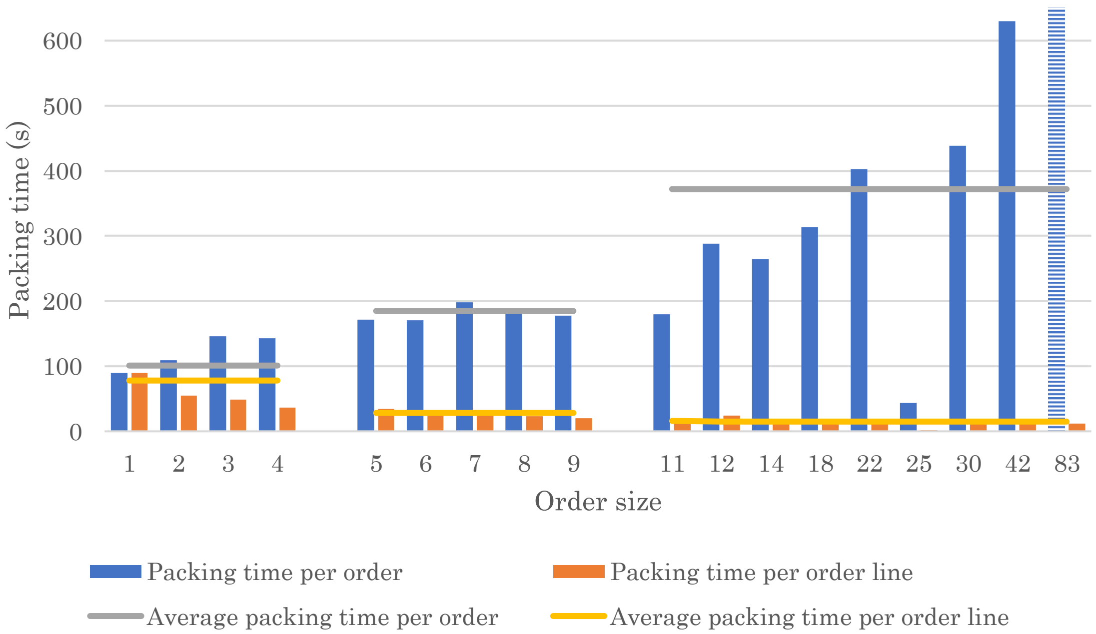

Figure 37: Packing time per order line for the three order size categories, BG excluded

5.3.1.3 Average Total Packing Time in the Future-State Process

As for the first time study, the packing time per order line excludes all BG orders. The additional study shows that it takes approximately 125,4 percent longer time to pack an order line included in a BG order as some of the waste has been eliminated. This number is then used to extrapolate the estimated packing time for the regular orders to compensate for the additional time that these orders require as the total time is being summed up, see Table 20.

Table 20: Average total packing time per day in the future-state

Order size	Average packing time/ order line	Average number of orders/ category	Average number of order lines/category	Total time
1-4 order lines	78 s	323	543	11h:45m:54s
5-9 order lines	28 s	46	361	02h:48m:28s
≥10 order lines	16 s	29	487	02h:09m:52s
		∑ = 408	∑ = 1391	∑ = 16h:44m:14s
BG extrapolation			16h:44m:14s * 7% * 1,254 =	01h:28m:08s
Total sum			∑ = 16h:30m:08s + 01h:28m:08s =	18h:12m:22s

The results from Table 15, section 4.2.2.6 and Table 20 show that the required number of packing hours decrease by 42 percent, from 31h:29m:08s to 18h:12m:22s. As such, the future-state process provides savings of 13,1 packing hours per day. Noteworthy is that time dedicated to the refilling of carton boxes and bubble wrap was not included as only the necessary steps to pack an order was timed in the second time study, meaning that some time for this will be demanded by either packing staff or other warehouse staff.

In addition to a shorter packing time, the inventory of consolidated orders in the consolidation area in the future-state process is eliminated and the waiting time is decreased significantly as orders proceed to packing as they have been consolidated.

Chapter 6

Design the Change

This chapter focuses on the third step of a Lean implementation process, previously described in Figure 8, section 2.2.1: Design the change. The chapter aims to answer RQ2: How can the packing process be redesigned for waste elimination by implementing warehouse automation and a new packing area layout? This is accomplished by developing a suggestion for a new layout for the packing area and mapping out the wastes that would be removed by implementing it. The first draft of the future-state map from section 5.3 is used as the baseline for an analysis of how the new packing area layout could be designed. In section 6.1, a received draft of a layout proposal is described. In section 6.2, suggestions for the final packing area layout, refined from the initial draft, are discussed after analysis. A discussion about how wastes are eliminated is held in section 6.3. Lastly, a cost-benefit analysis of a new layout implementation is conducted and described in section 6.4.

6.1 Description of the First Draft of a Layout Proposal

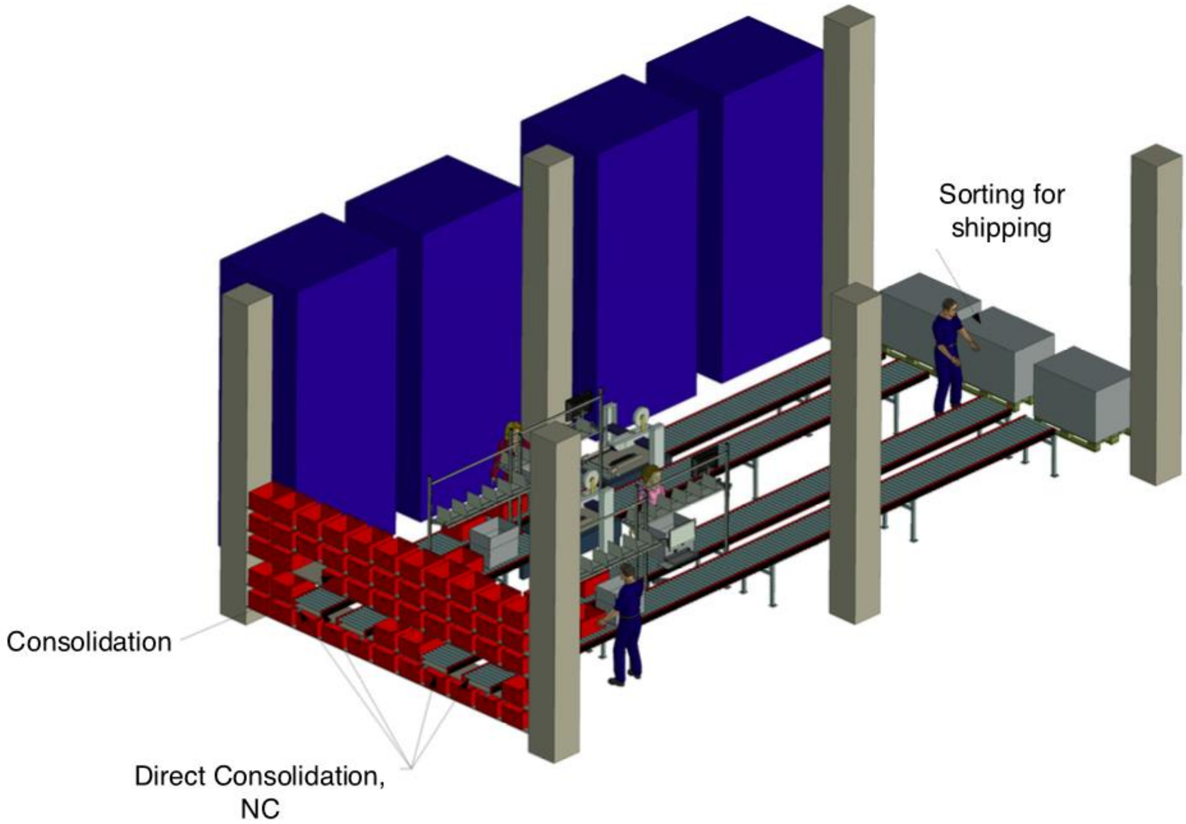

Figure 38: Draft of a layout proposal

Figure 38 illustrates a proposal for a new packing area layout that was received from a company specializing in strategic packing concepts two years ago. More illustrations can also be found in Appendix D.

By implementing the proposal, the packing system would shift from a man-to-goods system, where each packer walks up to the consolidation area and collects storage bins containing customer orders, to a goods-to-man system where a customer order will be transported to the packer by a conveyor system, hence eliminating traveling waste. As the picker who picks the last suffix for a customer order has placed the items in its storage bin, the picker will take the storage bin and put it on an inbound conveyor. The storage bin is transported directly to one of the packing stations, where the order will be packed. If several orders are released for packing in a short time slot, these will accumulate on the inbound conveyor while waiting to be packed. After the order has been packed, the package is placed on the outbound conveyor section, where it is transported to the end of the conveyor. There, another packer or a worker from dispatch could be responsible for sorting the package and putting it on the appropriate shipping pallet.

The costs of such a system would involve the costs of conveyors. Moreover, a tape-machine could also be installed to eliminate the non-value adding step of sealing each package.

Table 21: Cost proposal

COST DRIVER	COST
Gravitating conveyor	3.500 SEK/m
Tape-machine	45.000 SEK

6.2 Analysis of a New Packing Area Layout

The initial proposal resolves some of the waste that is built in the process but only represents a first draft, that needs further examination and development before implementation. When redesigning the layout for the packing area, there will be numerous aspects that have to be considered and parameters that need to be determined in order to find a layout that can handle the volumes efficiently whilst avoiding waste. These are categorized in Table 22 and will be further addressed in the following sections.

Table 22: Aspects and parameters that need to be addressed in the design of a new layout

ASPECT	PARAMETER
Consolidation area	• Storage bin size and the number of different sizes • Type of storage racks and the dimensions of them
Packers and Packing Stations	• Number of packers, and packing stations, that are required to handle the volumes in the packing process
Conveyors	• Number of conveyors for inbound and outbound transportation • Placement of conveyors in relation to the packing stations • Length of inbound and outbound conveyors
Packing station design	• Packing support equipment and placement of each of them • Floor space for each packing station • Type of workbench
Packing of DG	• Assignment and location for packing of DG
Storage of materials	• Storage location for carton boxes, bubble wrap and other packing materials

Staging	• Location of shipping pallets • Responsibility for sorting packages according to the transportation carrier

The layout will be designed with the ability to handle a growth of 20 percent. To gain an idea of the maximum flows in the warehouse, of which the new layout must be designed with the capacity to handle, snapshots from the three days that experienced the highest volumes during May 2019 are produced. From Figure 29, section 4.2.2.6, it can be concluded that 2019-05-07, 2019-05-14 and 2019-05-21 are the days that experience the highest volumes, based on the number of order lines that are registered for packing. The "worst case"-scenario is therefore more likely to occur during any of these days, which is why ERP data from these days are further analyzed to ascertain that the new layout will be able to handle the maximum levels that the packing process must have the capacity for.

6.2.1 Consolidation Area

The size of the consolidation area is dependent upon the number of customer orders that will be waiting for consolidation during peak hours. The results from data analysis show that the maximum number of orders waiting for consolidating in the DC is reached during 2019-05-07, as 51 orders are then waiting for consolidation. The snapshots for the entire day are displayed in Figure 39. During the analysis, all NC orders and consolidated orders that are waiting in the consolidation area for packing and not consolidation are excluded as these are not waiting for further consolidation even though they are occupying space in the consolidation area as it is currently designed.

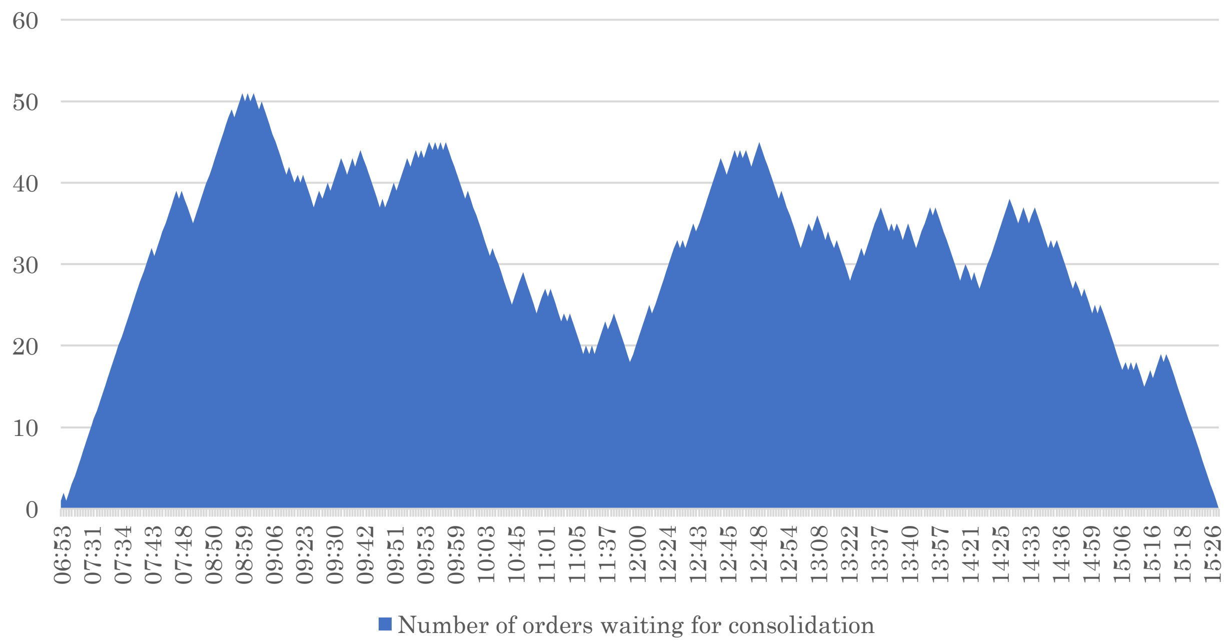

Figure 39: Snapshots of the number of orders waiting for consolidation during 2019-05-07

The size of the consolidation area will be determined by the number of orders that it intermediately stores, as well as the physical volume of each order. In the current-state process, orders are being consolidated in small- or medium-sized storage bins of the dimensions 23x29 cm and 37x41 cm. Due to the 2 meters long flow racks in the current consolidation area, each suffix must be put in a separate bin. This results in the usage of multiple storage bins even though the products could have fitted into one or perhaps two storage bins. The excessive number of storage bins demand space and ultimately result in double handling in the packing process, hence creating waste. Thus, one of the main goals in the design of the new layout is to minimize the use of excessive storage bins in the process. In order to do so, it is suggested to decrease the depth of each shelf and use storage bins with dimensions that enable minimization of the number of storage bins used for each customer order.

6.2.1.1 Storage Bin Size

Every customer order includes various numbers of order lines, each SKU with its individual dimensions. As a result of a high number or order lines or the dimensions of SKUs, all orders cannot fit into a single storage bin. However, a large portion of them can. By reason of the dissimilarities in size of different customer orders, it is recommended to use three different flows in the packing process, and two different types of storage bins for consolidation. A smaller storage bin with the dimensions 37x41 cm and a larger storage bin with the dimensions 41x58 cm are presumed to be able to store the remaining orders that are not requiring packing at a customized BG packing station. The depth of the racks could be one or two bins deep, where each bin and lane will only be reserved for one customer order. By making the racking depth shorter, the order will be accessible from the pickers side and make it possible to consolidate multiple suffixes in the same storage bin. Due to a shorter racking depth, cheaper racks like selective pallet racking could be used instead of the generally more expensive gravity flow racks (Conner, 2018; King, 2011). As for BG, the products are typically not suitable to be stored in bins as they represent a size that is too large.

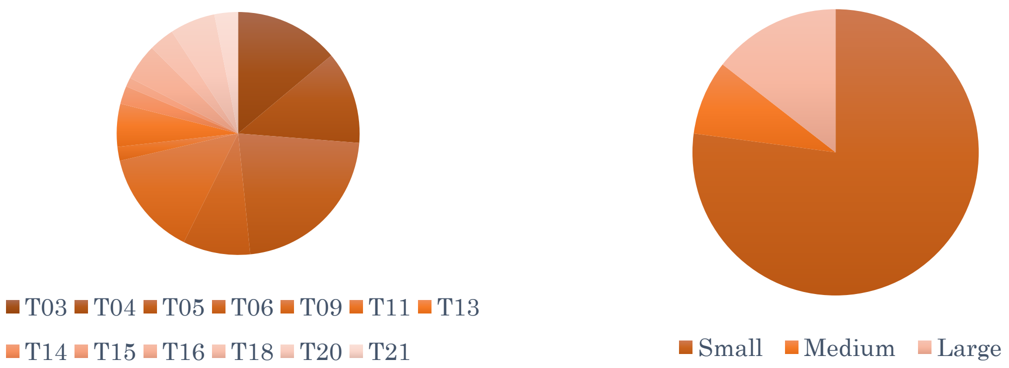

Figure 40: Frequency of use for carton boxes, concluded from ERP data from May 2019

Table 23: Size categories of carton boxes, based on the dimensions of cartons

CATEGORY	CARTON BOX SIZES	% OF ORDERS
Small (flow A)	T-03, T-04, T-05, T-06, T-09, T-13	77
Medium (flow B)	T-14, T-20	9
Large (flow C)	T-11, T-15, T-16, T-18, T-21	14

The dimensions of products are not registered in the WMS. However, the frequency of use for different carton boxes for packing can be derived from WMS data and used to indicate the physical volume of various customer orders as these dimensions are known. The data can then be used to map what type of storage bin that each order would potentially fit in during consolidation, to estimate the need for storage bins and the design of the consolidation area. The frequency of use for carton boxes can be found in Figure 40.

Figure 40 shows that the majority of orders, 77 percent, can be categorized as small based on the package size. From now on, orders of such sizes will be referred to as belonging to flow A. Medium-sized orders, referred to as flow B, represent 9 percent. Larger, including bulky, orders account for 14 percent and will be referred to as flow C. If the packing area would be divided into three separate flows, one for small-sized orders, commonly NC-orders, one for medium-sized orders and one for more bulkier goods like in the current set-up, the flows for each of them would vary in size. Flow A-orders could be consolidated in 37x41 storage bins and flow B-orders could be stored in one or multiple 41x58 storage bins. If different storage bins and types of storage racking would be used in the consolidation area for the different flows, the differences in flow size must be reflected in the fraction of the consolidation area that is dedicated to the storage of each flow.

6.2.1.2 Dimensions of the Consolidation Area

The number of orders waiting for consolidation cannot be affected by the throughput in the packing process, but is dependent on the efficiency in the picking process. The sooner the pickers can consolidate all suffixes for an order, the sooner the order is available for packing and can be removed from the consolidation area. Considering a growth of 20 percent, the consolidation area must be able to store 61 different customer orders waiting for consolidation, divided across the three flows. The size of the consolidation area can be calculated by considering the number of storage bins for each order and each flow, and the dimensions of each of them. As previously mentioned, the dimensions are not recorded in the ERP system, whereas some assumptions must be made in order to arrive at an estimate for the number of storage bins that will be needed for consolidation. From comparing different carton boxes, it is assumed that orders within flow A will fit in a storage bin with the dimensions 37x41 cm. Similarly, it is assumed that orders within flow B can fit into a storage bin with the dimensions 41x58 cm. The percentage which each flow represents out of the total number of orders, summarized in Table 23, section 6.2.1.1, are then considered.

Table 24: Dimensions for consolidation area

FLOW	NUMBER OF BINS	DIMENSIONS PER BIN	STACKING HEIGHT/ DEPTH	TOTAL WIDTH OF CONSOLIDATION AREA
A	0,77 * 61 ≈ 47	37x41 cm	5 bins/ 1 bin	(47*0,4)/5 = 3,76 m
B	0,09 * 61 ≈ 5	41x58 cm	5 bins/ 1 bin	(5*0,45)/5 = 0,45 m
C	0,14 * 61 ≈ 9	37x41 cm, 41x58 cm	5 bins/ 1 bin	(9*((0,4+0,45)/2)/5) = 0,77 m

Each level in the current flow racks has a height of 22 cm. To be able to stack more items in some of the storage bins and hence decrease the required number of storage bins, it is suggested to have one or two levels that have a height of at least 30-40 cm for flow B. The stacking height can be 5 storage bins and the depth is recommended to be one storage bin.

One challenge with this set-up is that the dimensions of each order line are not included in the WMS and visible to the pickers that are sorting the customer orders. Neither is there a correlation between the number of order lines and the physical volume of an order. This means that the picker that arrives to the consolidation area with the first suffix of the order would not for certain know how much space that the order will require for consolidation, since it is dependent upon the dimensions of other SKUs that are yet unknown to the picker. Today, the same issue is faced by the pickers for the consolidation of BG. If the first suffix is considered as bulky, that suffix and the remaining ones will all be consolidated at the shelves by the BG station. However, if the bulky items are not picked until later on, some suffixes will be consolidated in either the A- or B-section, and the remaining suffixes in the C-section of the consolidation area. If different suffixes would be consolidated at multiple sections with the new layout, the suggestion is to follow the same procedures as today. Excessive capacity in the consolidation area for flow A and B would be necessary. Therefore, it is further assumed that there is a possibility that a part of the flow C-orders will be stored in storage bins within the consolidation area A and B, see Table 24, and not on the shelves that are dedicated to the BG for consolidation of flow C-orders. Ultimately, additional space should be added to the consolidation area for flow A and B to store partial orders from flow C that are not considered as bulky. The total width of the consolidation area for this is approximated to 0,77 m. Additional space could also be added to the consolidation area as the same issue could be faced by pickers that are consolidating flow A- and B-orders. Preferably, the different sections of the new consolidation area should be located in proximity to each other, to eliminate travel in between the different sections whenever orders are consolidated within multiple sections.

Moreover, there needs to be space left by the consolidation racks for conveyor lanes to be accessible from the pickers side. This will depend on the number of conveyors, which will be addressed in section 6.2.3.

6.2.2 Number of Packers and Packing Stations

The required number of packers and packing stations are dependent upon the packing time, volumes and fluctuations in volume. In Table 20, section 5.3.1.3, the average packing time in the future-state process was estimated to be 18h:12m:22s. This number also includes the packing of BG. With an 80 percent utilization rate of employees, this would imply that 3,9 operators are needed if a 20 percent growth is accounted for ((18h:12m:22s/07h:00m:00s)*1,25*1,2), including all flows; A, B and C. As of today, 3,25 operators would on average be needed in the future-state process if there was available work for them throughout the day.

However, considerations need to be taken not only to the average volumes, but also to the variations in volume throughout the day as a result of the different order deadlines and the times when orders are being picked and consolidated, hence made available for packing. To assess how many orders that need to be packed per time unit, data on order deadlines for the packing process is analyzed. The speed of which packers can pack the orders are then accounted for to compute the number of packers that need to be working in the packing area. As a result of a higher throughput in the later afternoons, this throughput requirement will determine the number of packing stations that are needed, to enable additional packers to step in as required.

In order to analyze how many orders that need to be packed per time unit more deeply, snapshots from the three days that experienced the highest volumes during May 2019 are produced. This shows that the highest volumes are experienced during 2019-05-07, which is why data from this date is further analyzed as the required number of packing stations are to be determined. From Figure 41, it can be concluded that the vast majority of orders have an order deadline for packing at 16:30. However, if such orders can be consolidated sooner, they can be packed much earlier, hence decreasing the workload close before 16:30. As can be interpreted from Figure 42, orders with a 16:30 deadline are picked and made available for packing throughout the day.

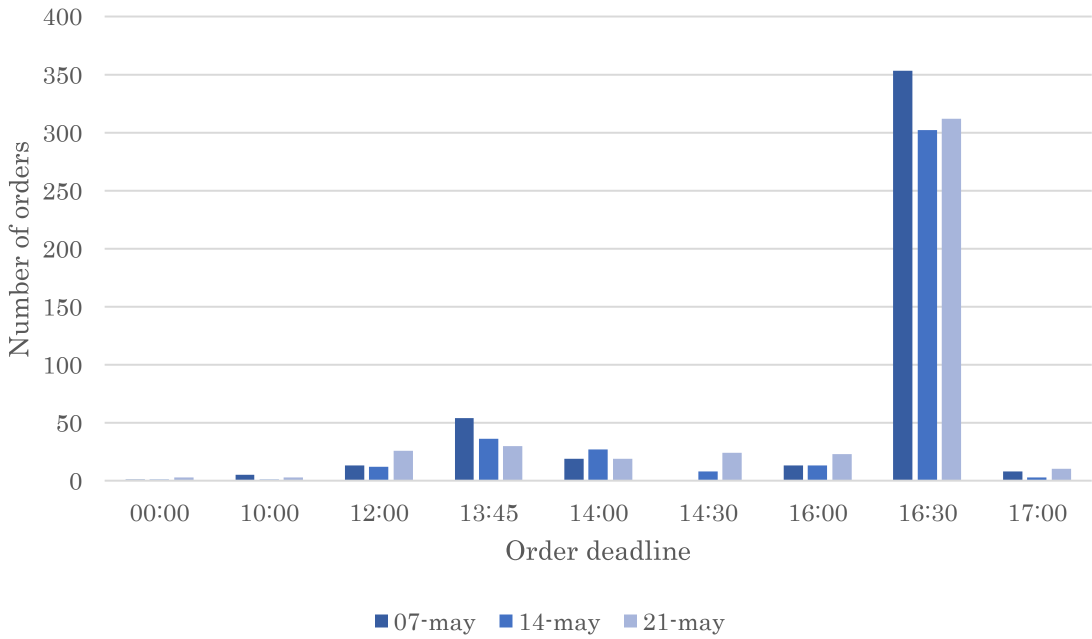

Figure 41: Order deadlines for packing during peak days in May 2019

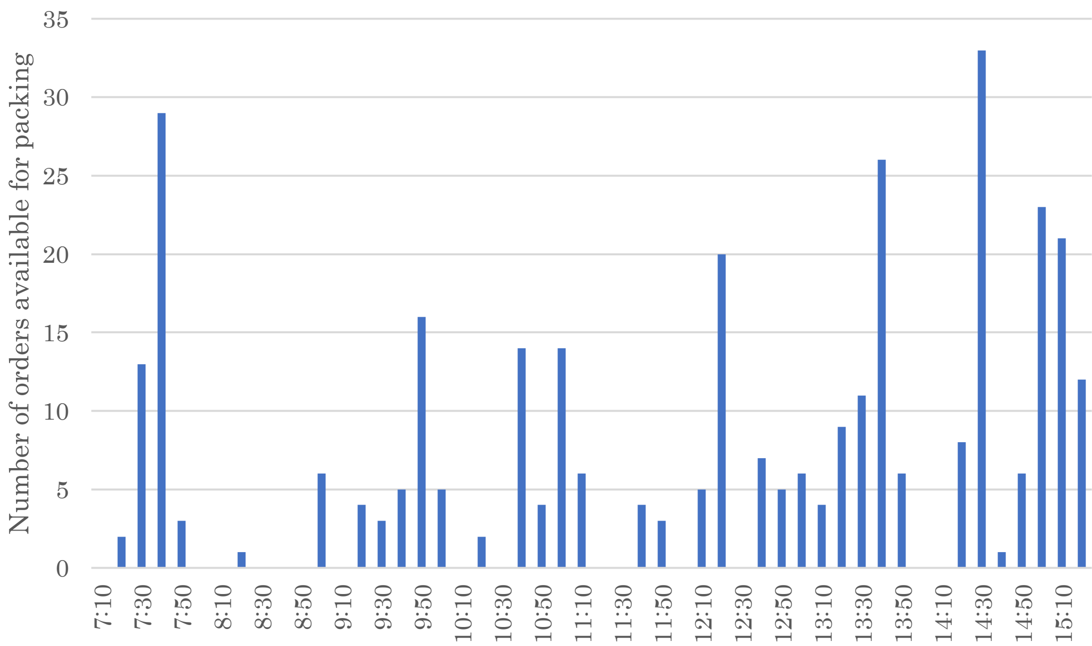

Figure 42: Timestamps from when the orders with a 16:30 deadline are available for packing, during 2019-05-07

6.2.2.1 Number of Packers and Packing Stations for Flow A and B

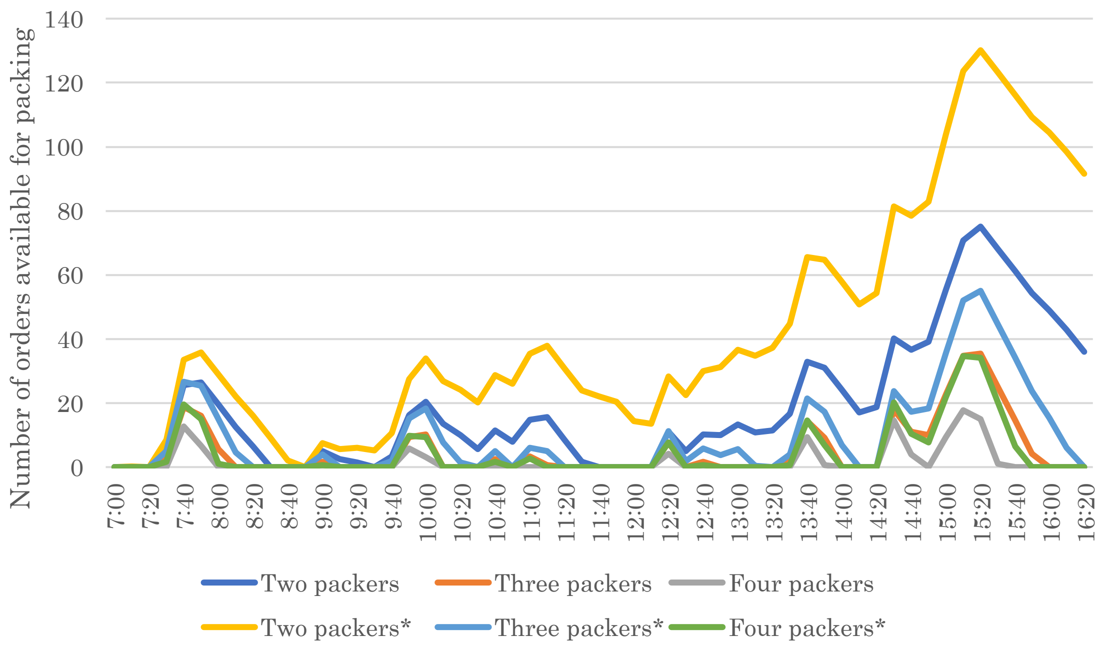

*Figure 43: Analysis of the required number of packers for flow A and B. * 20 percent growth is accounted for*

The results displayed in Figure 43 have been calculated by considering a packing time of 2,3 minutes per order and a utilization rate of 80 percent for each employee. 14 percent of orders are deducted, to exclude more bulky orders which will be included in flow C, assuming the distribution of timestamps for each flow to be similar. Flow C can then be analyzed separately. The results show that no more than three packers would be needed to pack orders that are not considered as bulky in the current set-up. Figure 43 also shows that three packers are not always required, as whenever the number of orders available for packing is at zero for any period of time, this implies that the throughput is lower and does not justify having three employees dedicated to packing at that time. However, if a 20 percent growth is taken into considerations, four packing stations could be considered to hedge against uncertainties.

6.2.2.2 Analysis of Throughput Requirement considering Order Size Distribution

A factor which has a high impact on the required number of packers and packing stations is the average order packing time that was estimated from the time study to be 2,3 minutes. When the total packing time for the two days of observations, as well as the average packing time, were calculated in section 4.2.2.5 and 4.2.2.6, the combined results showed that it is not only the total number of orders or order lines, but also the distribution of order sizes that will impact the total order packing time, and ultimately the average order packing time per day. Since the packing time per order line is higher for small order sizes (1-4 order lines), constituting flow A, a higher fraction of such orders will increase the total packing time even if the number of order lines would remain the same. Therefore, a "worst case"-scenario for the order size distribution must be analyzed. The results are illustrated in Figure 44. The highest daily total number of order lines for orders containing 1-4 order lines are 681 order lines, or 52 percent of the total number of order lines, during 2019-05-28.

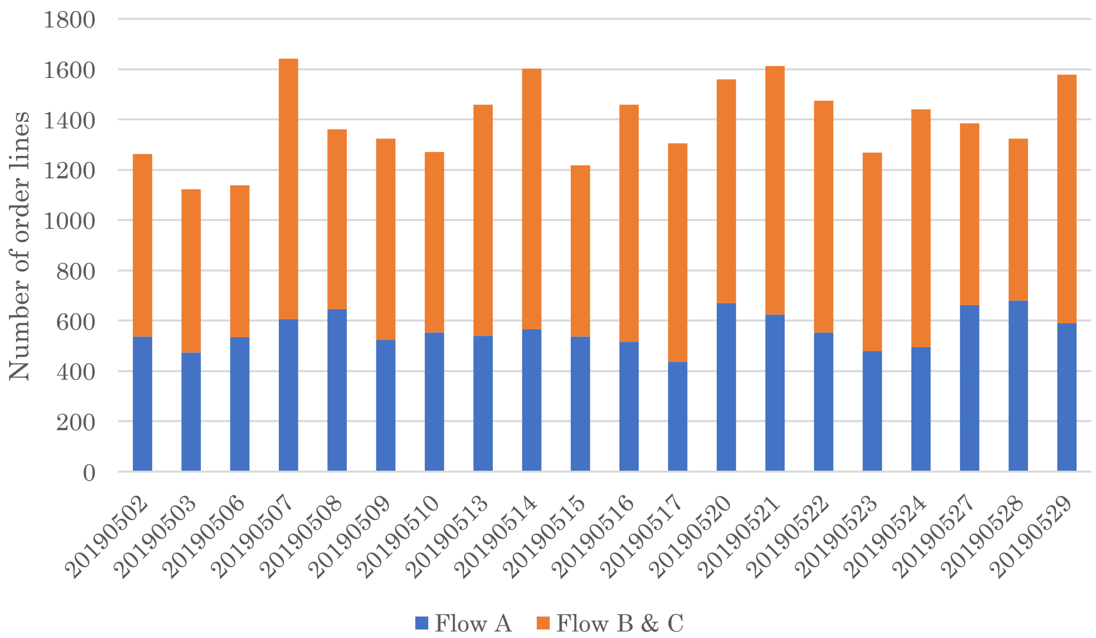

Figure 44: Number of order lines for orders of small order sizes as a fraction of the total number of order lines

The results from Table 25 show that the total order packing time would increase to 22h:20m:30s, hence an increase of 33 percent from the estimated average of 16h:44m:14s, see Table 20, section 5.3.1.3. A simplified way of accounting for this in the analysis, is to estimate that the average packing time would increase uniformly, from 2,3 minutes to 3 minutes. Figure 45 shows the impact that this will have on the required number of packers. To hold the capacity for a 20 percent growth during a day with a worst-case order size distribution, four packing stations would be required for flow A and B.

Table 25: Throughput capacity requirement for the future-state process, considering the maximum number of order lines and a worst-case order size distribution

Order size	Average packing time/ order line	Average number of order lines/ category	Total time
1-4 order lines	78 s	0,52 * 1642 ≈ 853	18h:28m:54s
5-9 order lines	28 s	0,25 * 1642 ≈ 411	3h:11m:48s
≥10 order lines	16 s	0,23 * 1642 ≈ 378	1h:40m:48s
Total		∑ = 1642	22h:20m:30s

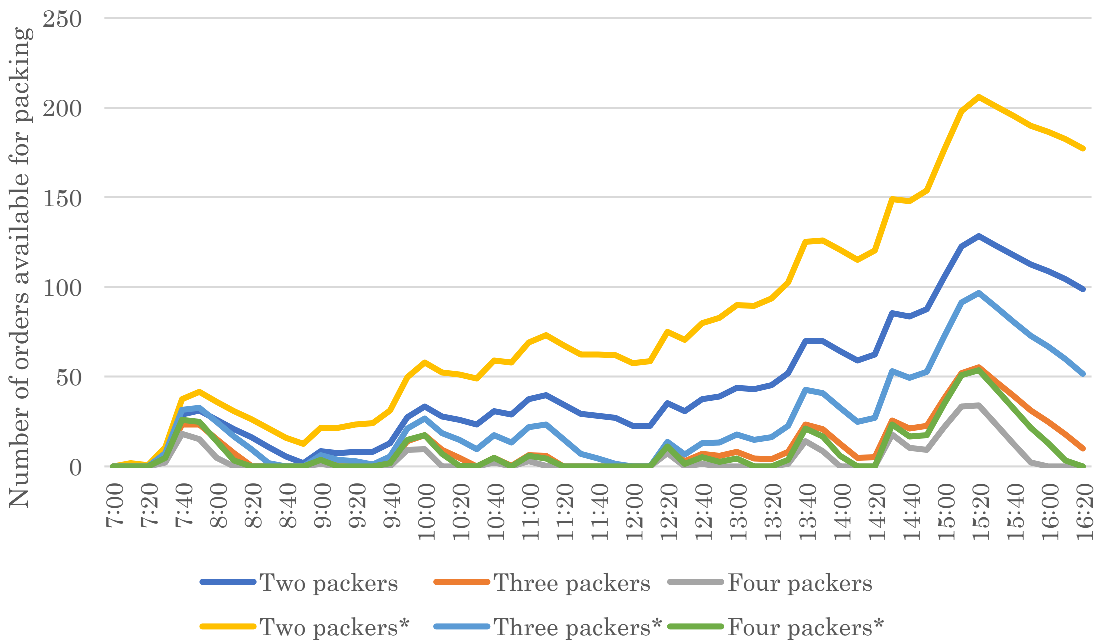

*Figure 45: Analysis of the required number of packers for flow A and B, considering worst-case order size distribution- * 20 percent growth is accounted for*

6.2.2.3 Number of Packers and Packing Stations for Flow C

The packing process for BG orders, representing 14 percent of all customer orders, differs as BG will generally have a greater need for special handling in the packing process. Therefore, the average packing process time for BG orders is higher than the average packing process time for other orders. According to the second time study, the packing time in the future-state process would be approximated to 4,4 minutes for BG orders, representing a 91 percent increase compared to the packing time of 2,3 minutes as estimated for regular orders. The results displayed in Figure 46 have been calculated by considering a packing time of 4,4 minutes per order and a utilization rate of 80 percent for each employee. To account for worst-case order size distribution, as was done for flow A and B, an increase of 33 percent is added to the estimated average, meaning the packing time would then be approximated to 5,9 minutes. 86 percent of orders from the snapshots are deducted, in order to only take considerations to the number of orders for flow C. Doing so assumes that the distribution of timestamps for each flow is similar. From Figure 46, it can be concluded that one packer is required when a growth of 20 percent growth is considered. Considering the possibility for a worst-case order size distribution and a growth of 20 percent, two packers would be required to pack all BG orders in time for the 16:30 order deadline.

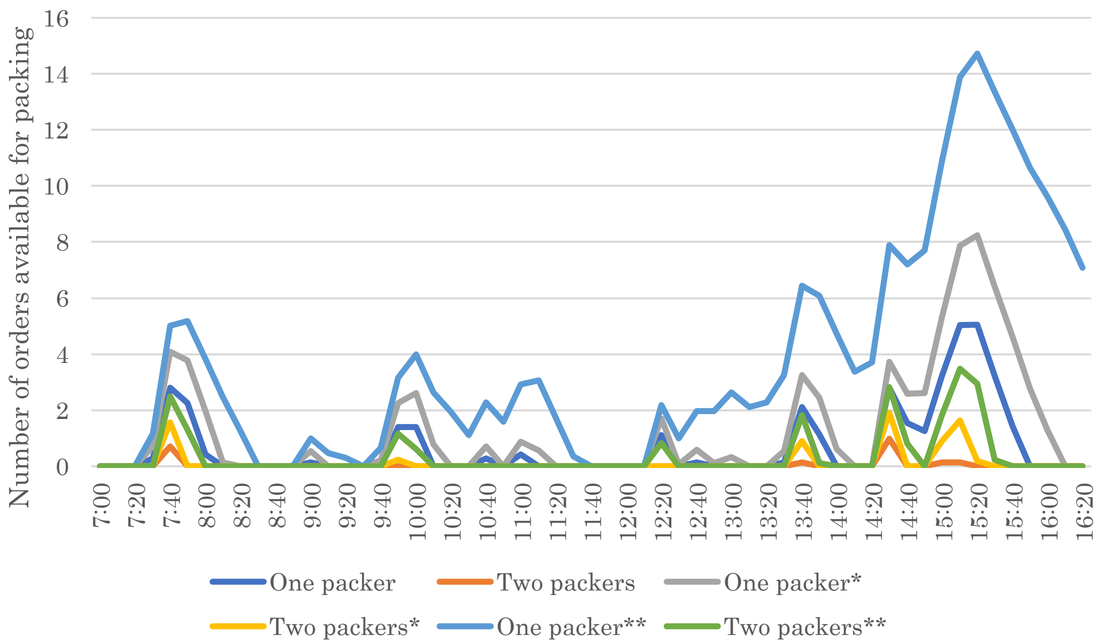

*Figure 46: Analysis of the required number of packers for flow C. * 20 percent growth is accounted for. ** Worst-case distribution of order sizes and 20 percent growth are accounted for*

6.2.2.4 Working Schedule

Although the new packing area must be designed to handle both fluctuations in order sizes and future growth, every packing station will not be operated by a packer every day and during the entire shift since the volumes will fluctuate. Figure 47 aims to provide an idea of the number of employees that will be needed on the packing team during a day experiencing high flows, meaning the number will usually be lower. The data includes packing of all flows. The number of packers increases from two to four as the workload increases during the day.

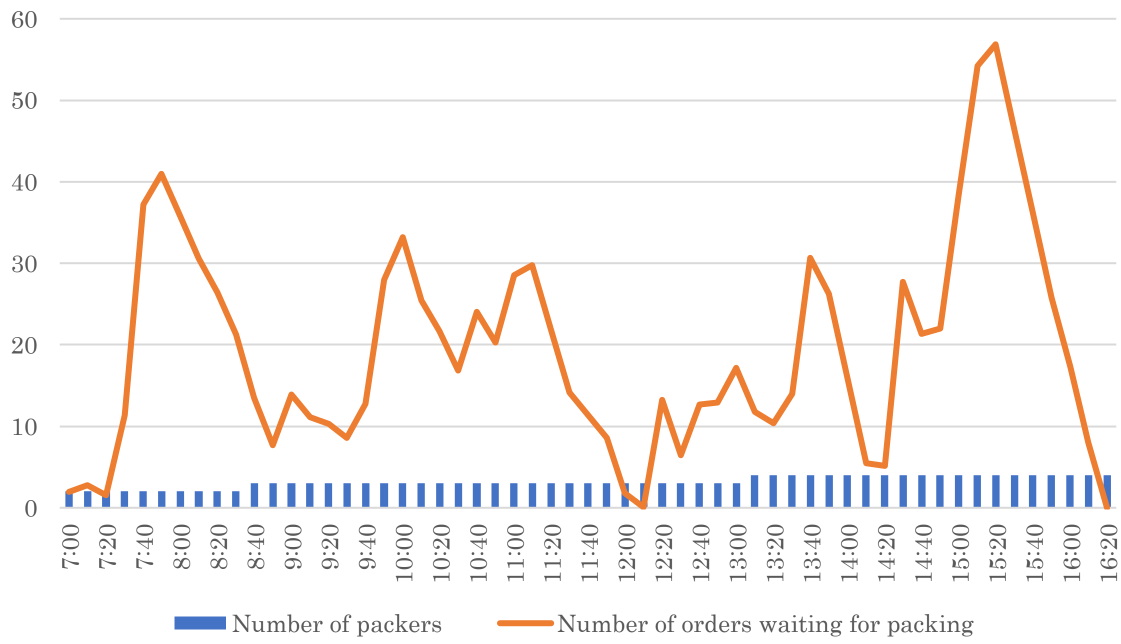

Figure 47: Potential working schedule, based on ERP data from 2019-05-07

6.2.3 Conveyors

To decrease the cost of conveyors, gravitating conveyors should preferably be used. One important step in the design of the layout is to determine the minimum length of the inbound conveyor that is long enough to assure that gridlocks are avoided and prevent congestion in a conveyor lane. On the contrary, a too long conveyor will take up unnecessary space and be more costly to install. When computing the required conveyor length the following aspects must be considered:

- The maximum number of orders that are waiting for packing during any point in time in the packing area
- The speed that the packers are able to empty the lanes
- The conveyor space that each order preoccupies in a "worst case"-scenario
- The number of conveyors that the orders can be accumulated on while waiting to be packed

6.2.3.1 Conveyors for Flow A and Flow B

To estimate an appropriate length of conveyors, the maximum number of accumulated orders that have been consolidated and proceeded to the next step; packing; needs to be established. The timestamps for when NC orders arrive to the packing area as well as whenever a consolidation order has been fully consolidated are analyzed.

The results displayed in Figure 48 have been calculated by considering a packing time of 2,3 minutes per order and a utilization rate of 80 percent for each employee. About 14 percent of orders are deducted, to exclude more bulky orders which will be included in flow C and analyzed separately. Results show that the maximum number of orders that are available and waiting for packing is 34 if a 20 percent growth is considered.

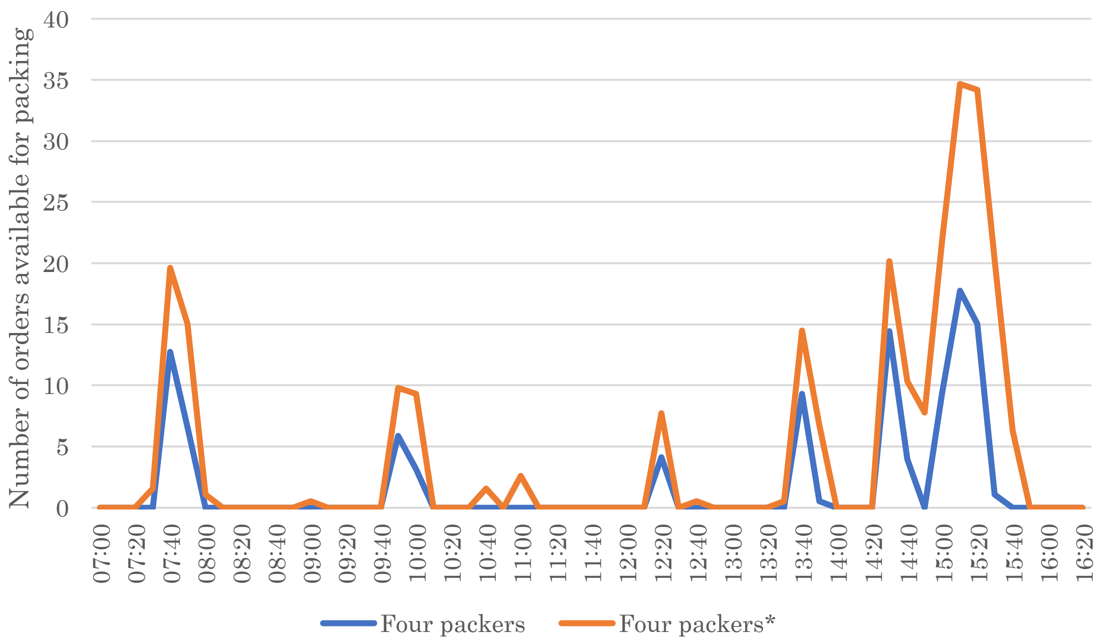

*Figure 48: Analysis of the required conveyor space for flow A and B. * 20 percent growth is accounted for*

The conveyor space that each order would need can be calculated by considering, the number of storage bins within each order and the dimensions of each of them. As previously mentioned, these are not recorded in the ERP system, whereas some assumptions must be made to arrive at an estimate for the number of storage bins that will need storage on the conveyor lanes. From comparing different carton boxes, it is assumed that orders within flow A will fit in a storage bin with the dimensions 37x41 cm. Similarly, it is assumed that orders within flow B can fit into a storage bin with the dimensions 41x58 cm. It is also assumed that if an order is being consolidated in both a 37x41 bin and 41x58 bin, due to the challenges and procedures explained in 6.2.1, these orders are consolidated into the same storage bin before being put on a conveyor. The percentages which each category represents out of the total number of orders, summarized in Table 23, section 6.2.1, are then considered. The results from calculations in Table 26 show that 11,26 meters of conveyor is required for flow A and 1,46 meter is required for flow B.

Table 26: Conveyor space requirement for flow A and B

CATEGORY	SPACE (M)
Flow A	0,77/(0,77 + 0,09) * 34 * 0,37 = 11,26
Flow B	0,09/(0,77 + 0,09) * 34 * 0,41 = 1,46
	∑ = 11,26 + 1,46 = 12,72

The number of packers and packing stations for flow A and B that would be needed was computed in section 6.2.2.1. Two set-ups could be used for the number of conveyors: either, there could be one or two conveyors that transport the consolidated orders to multiple packing stations. Moreover, each packing station could have its own conveyor belt which would only transport orders to that particular packing station. The benefit of the first set-up would be a decrease in the costs of conveyors. The advantage with the second set-up is that more orders could be accumulated on an increased number of conveyors, without having to extend the length of the conveyors considerably to fit all accumulated orders. Moreover, each packer would have ownership of its own conveyor lane, which could have a positive psychological impact on work efficiency besides providing the advantage of eliminating traveling completely.

Moreover, the length of the outbound conveyor should be determined. The length is dependent on the speed of which packers are packing the orders, the dimensions of packages as well as the frequency of which one wishes to sort the packages that will accumulate on the outbound conveyor section. A longer conveyor would decrease the required frequency of the sorting process. The trade-off is that the conveyors would take up more space in the packing area.

6.2.3.2 Conveyors for Flow C

If the BG packing stations are going to be equipped with conveyors, these will need to be wider to fit both the goods before packing, as well as the larger packages on the outbound conveyor. The maximum width of any SKU packed in the light packing area will direct the width of the conveyors. In turn, the length of the inbound conveyor is subject to many uncertainties. Since gravitating conveyors will be used, fragile items would preferably be put in larger storage bins for protection, as the items might be lying on the gravitating conveyor belt for several minutes. Larger, pre-packed packages would however not require to be placed in storage bins.

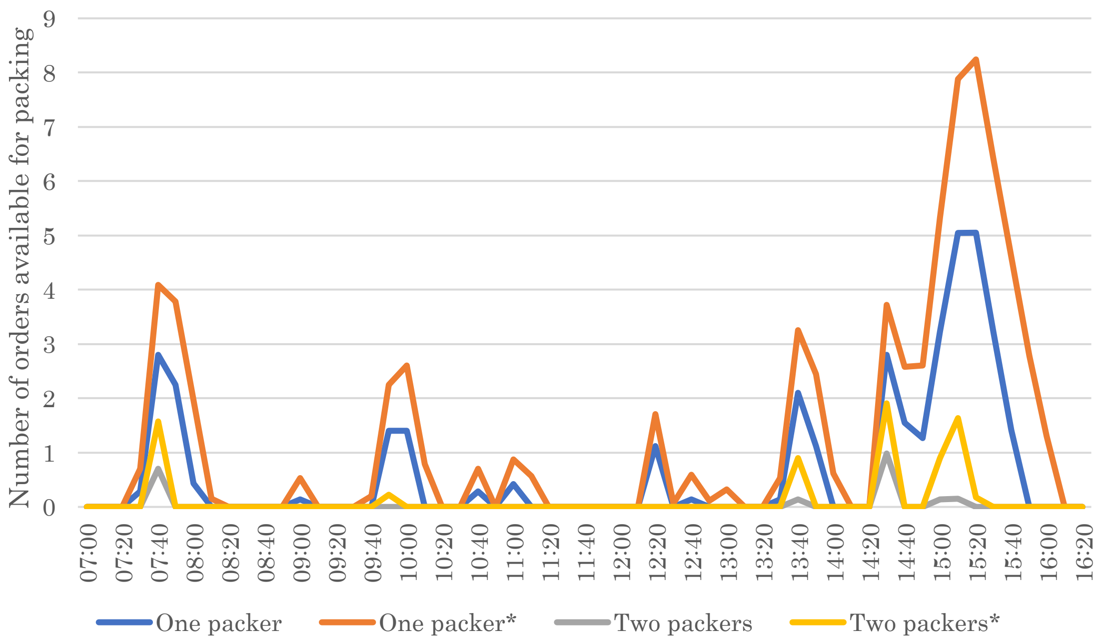

*Figure 49: Analysis of the required conveyor space for flow C. * 20 percent growth is accounted for*

The results displayed in Figure 49 have been calculated by considering a packing time of 4,4 minutes per order and a utilization rate of 80 percent for each employee. Only 14 percent of orders are included as the analysis is only considering flow C.

The results show that the maximum number of orders that are available and waiting for packing is two customer orders when two packers are operating flow C and a 20 percent growth is considered. However, just like today, it is likely that the packing station for BG most often will be operated by a single packer, although it will be possible for a second packer to step in as required since a second packing station is installed further down the conveyor line. If a single packer is dedicated to flow C, more orders will accumulate during certain timespans. The results from Figure 49 show that about eight orders can be waiting on the inbound conveyor when a 20 percent growth is accounted for. Since the majority of products within each flow C-order will not be intermediately stored in storage bins during consolidation, assumptions with regards to the conveyor space the orders will require will need to be made. Considering that 12,72 meters were estimated to be sufficient to store 34 orders, these numbers could be used as a reference point. If the inbound conveyor length is divided equally across four packing stations, each of them must be at least 2,74 meters (12,72/4 = 3,18 m). This means that 3,18 meters are required to store 8,5 orders (34/4), or that each order adds 0,37 meter to the conveyor. Seeing this, 8 orders would need at least 2,96 meters (0,37*8), and likely even more as the products in flow C are generally demanding more space due to the bulkiness of the goods.

6.2.4 Packing Station Design

Issues regarding the packing station design are mainly prominent in the BG packing stations. To decrease motion waste, it is recommended to install sliding shelves to a new workbench. By installing such shelves in these stations, packers will not have to pack bulky orders directly on the floor or on trolleys, waste 5.1, due to a lack of space on the workbench. Neither do they then need to lift and carry a heavy package over to the workbench for it to be weighed on the scale. Besides updating the workbenches with a sliding shelf at the flow C-packing stations, no recommendations on installing new workbenches will be made.

In addition to this, the printer should be placed elsewhere to allow shorter packers to lower the table and achieve improved ergonomics. Since the current tables can be height-adjusted, the advantage of the feature can then be realized. It also seems like not all packing stations are equipped with holders for bubble wrap. This should be assured in the new layout.

In the current layout, the packing stations are only equipped with the smaller carton box sizes, which would be sufficient for the packing stations operating flow A and flow B. If the new packing station for flow C could store larger carton boxes like T-16, T-18 and T-20, this would eliminate the need for traveling for carton boxes. This waste could also be reduced by storing such larger carton boxes in other accessible locations, close to the packing stations for flow C.

6.2.5 Packing of DG

There exists traveling waste by reason of that DG are often being packed at packing stations which are lacking the necessary labels and equipment. Packing station 13 is generally not being used but mainly functions as a storage location for such labels and equipment. As a result, packers need to engage in unnecessary travel. Since DG only represent less than 0,5 percent of total customer orders, this waste is not significant. However, it could easily be eliminated by operating a packing station that is equipped with everything that is necessary for the packing of DG, alike packing station number 13. One employee that has gone through the required training could be assigned the responsibility of DG and operate this packing station for each new day. Pickers should be notified so that they could then place DG on this lane as the order has been consolidated and can proceed to packing. For clarification purposes, a sign could also be put over the applicable conveyor lane.

6.2.6 Storage of Materials

From observations, traveling waste whenever refilling bubble wrap and some carton sizes at the packing stations have been identified. If the storage of these materials could be positioned in a more convenient location, this waste can be reduced. One idea is also to have other employees rather than the packers to be responsible for the refilling of necessary materials. In this way, the throughput in the packing process would increase as packers would no longer take breaks to refill bubble wrap, cartons, etc.

6.2.7 Staging

It would be beneficial to stage pallets with packaged customer orders closer to the dispatch area, to minimize traveling waste within the dispatch function. In the current layout, the area closest to the dispatch area is used for the storage of necessary materials. It is of the author's belief that this area could be used more wisely. The shipping pallets are located on each side of the aisle, see Figure 19, section 4.1.2. Packers are therefore often required to cross the aisle, hence being exposed to the risk of walking in the way of by-passing forklifts. Therefore, it is suggested to stage packages of customer orders on shipping pallets on the far end of the packing area, at the far end of the packing stations. This would minimize travel during the packing process as well as the shipping process, ultimately reducing waste.

6.2.8 Layout Proposal

The physical constraints of the packing area within the facility need to be considered before the final layout proposal is set as the proposal must be physically feasible to implement. The physical layout constraints of the packing area are measured and illustrated in Figure 50. Although not displayed in the Figure, the current packing tables have been measured to 2x0,9 m.

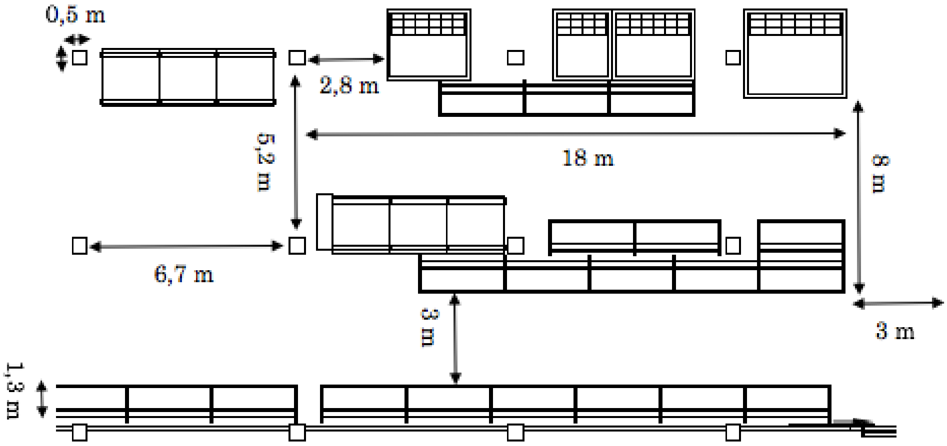

Figure 50: Physical layout constraints

The physical layout constraints of the packing area allow for the implementation of the suggested proposal resulting from the analysis in the previous sections. For example, the width of the space designated for the consolidation area, 5,2 meters are not limiting the proposal of the new consolidation area and five different lanes can be configured in parallel to each other as the flow in the packing process moves in another direction. Four drafts of a layout proposal are illustrated in Figure 51-54. The four proposals share the same main configurations but slightly differ. The second proposal, see Figure 52, shows how the layout can be configured to provide more storage space for materials. The trade-off is an increase in travel in the staging process as the length of outbound conveyors for packing stations 1-4 then must be shorter. In the third proposal, see Figure 53, packing station 3 is located in another position along the conveyor in order to increase the available floor space for the packers who are operating packing stations 2 and 3. However, this will imply that the incoming conveyor is considerably longer than the outgoing conveyor and that not as many packages can be accumulated on the outgoing section before requiring sorting to a shipping pallet. In the fourth proposal, see Figure 54, flow C is operating similar to how the current BG packing stations operate today. There is no inbound conveyor belt to packing stations 5 and 6, but these are located closer to the consolidation racks. This solution could be implemented if believed that BG is not suitable to be transported on conveyor belts, whereas conveyor belts could only be leveraged for transportation of sealed packages on an outbound conveyor.

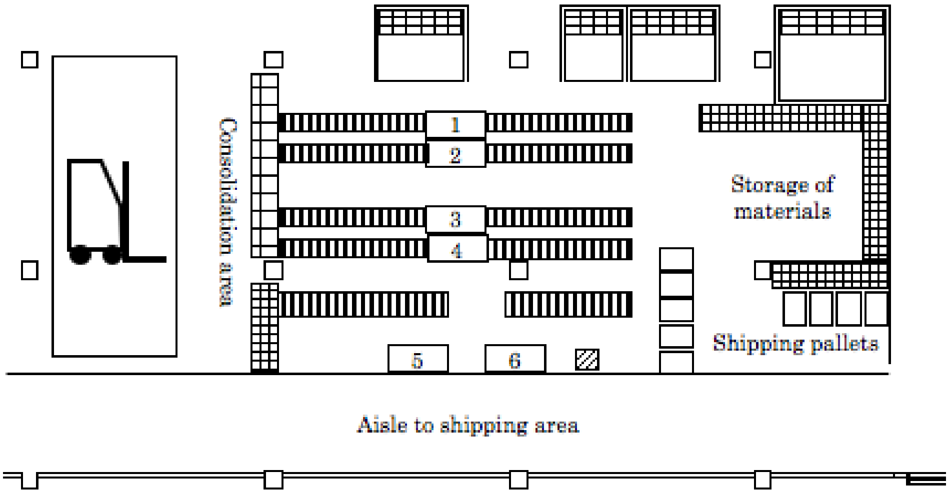

Figure 51: Layout proposal 1

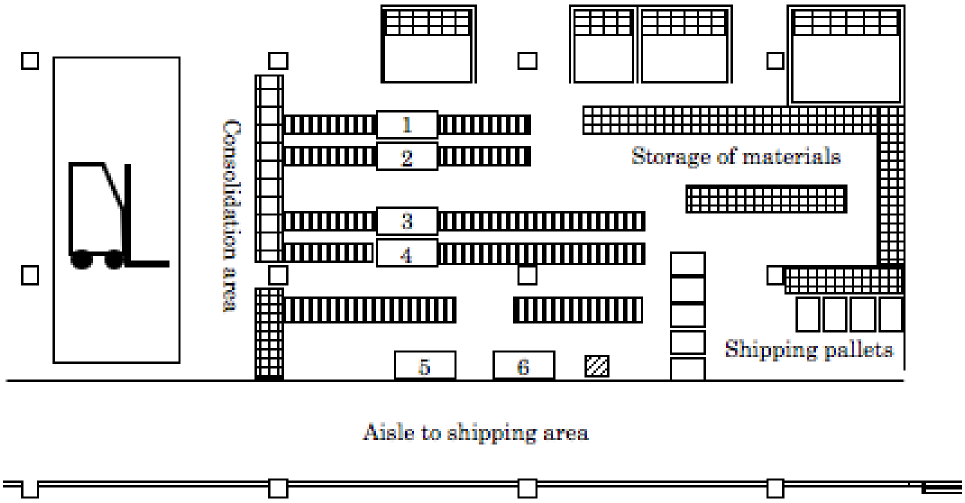

Figure 52: Layout proposal 2

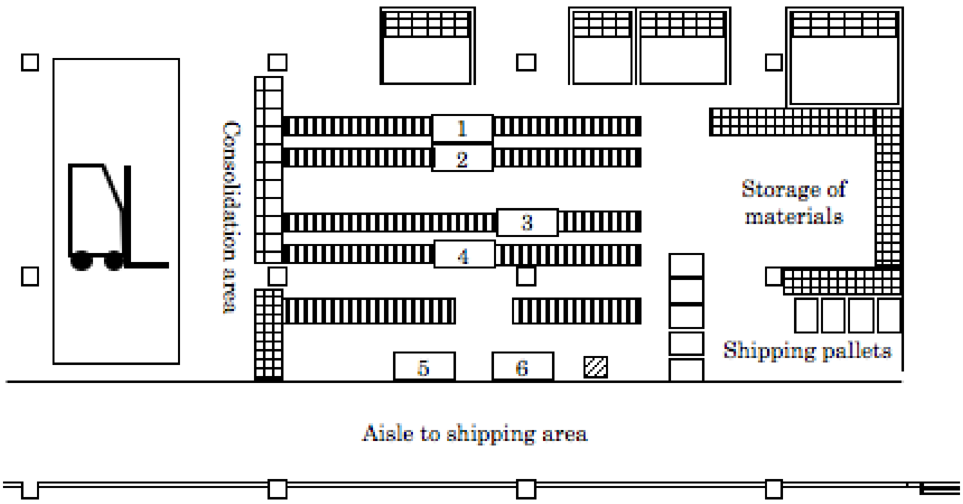

Figure 53: Layout proposal 3

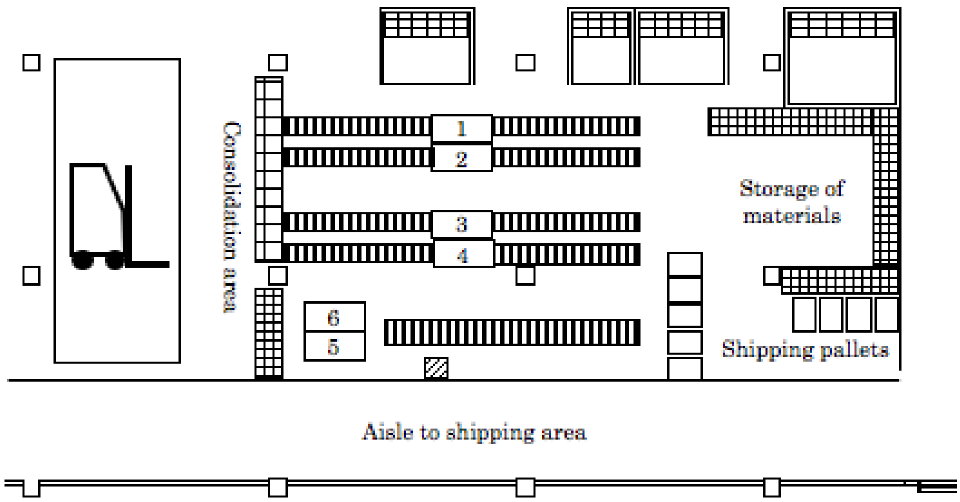

Figure 54: Layout proposal 4

In all of the proposals, four packing stations can be used for flow A and B, here numbered 1-4, and two packing stations can be operated for flow C, here numbered 5 and 6. For flow C, the set-up is slightly different as the two packing stations are using the same conveyors. This design is chosen mainly for two reasons. Firstly, the physical layout constraints illustrated in Figure 48 do not allow six packing stations to be operating its own conveyor with this configuration. Secondly, moving the packing of flow C-orders to the heavy packing area, not visible in the figure, would result in waste whenever parts of the order is being consolidated in the consolidation area for flow A- and B-orders, that are then packed by any of packing station 5 or 6 together with the more bulky SKUs within the customer order. By putting them in proximity to each other, this waste can be prevented.

To eliminate the risk for personnel to walk in the way of by-passing forklifts, the aisle in between MO as well as the heavy packing area, and the shipping area, are moved to the wall, hence removing the storage space in between the wall and the aisle. This will also eliminate traveling waste. If the aisle could be completely removed, more floor space could be allocated to the packing area. However, this would increase the traveling waste within the other outbound processes, which is why it is not recommended. Moreover, the space that is currently hosting the packing stations now consists of a truck zone, where pickers will park the trucks as they are performing the process of consolidation.

The shipping pallets are, as previously discussed, located closer to the dispatch area. The storage of necessary materials are now located closer to the packing stations as these have been moved closer to the materials' storage locations. Although not illustrated in any of the figures, the proposal includes having a reverse conveyor system beneath the regular conveyor system. One suggestion also includes having carton boxes stored more accessible, perhaps underneath the conveyors. If this would be feasible, this space would be used more efficiently. The benefit of dividing the total flow into three flows, each flow demanding different sizes of carton boxes, is that it implies that only some of the carton boxes must be put in the most accessible locations. For Flow A and B, the applicable carton boxes can be stored on the shelves above and beneath the packing station, as is the case today. For flow C, the space in between and on each side of packing stations 5 and 6 could be used to store larger carton sizes that are often used for packing of orders of larger sizes. The strapping machine should preferably also be located in proximity to packing stations 5 and 6, as the machine is generally used for the sealing of larger packages. In the figures, it is depicted next to packing station 6.

6.3 Eliminated Wastes

The following sections will explain how waste will be eliminated by implementing the proposal for a redesign of the packaging area that was described in section 6.2. By implementing the proposal, all of the 21 of the wastes will be reduced or eliminated. These include all wastes that have been identified and which are caused by the design of packing area layout, see sections 5.1 and 5.2. Elimination of the remaining wastes out of the ones identified is further addressed in Appendix C, see Table A2, section C.2.

6.3.1 Traveling

By using conveyors in a goods-to-man packing system, the traveling wastes 1.1 and 1.2 are eliminated. Waste 1.3 and waste 1.4 are not just causing waste in the form of unnecessary traveling. The packers are also exposed to the risk of walking in the way of by-passing forklifts, potentially resulting in fatal accidents. By installing conveyors for transport of packages and storing cartons in another location, this waste and potential risk will decrease. Waste 1.4 and 1.5 are removed by the use of outbound conveyor systems for the transportation of packages. Waste 1.3 and 1.6 are reduced to the extent that is possible by putting the storage space in a more convenient location, closer to the packing stations than today. Waste 1.7 is removed by a reduction in the number of storage bins that are being used as well as by adding a conveyor that can transport empty storage bins back to the new consolidation area. The final travel waste that is eliminated is waste 1.8. This would be accomplished by assigning DG goods to a packing lane that is operated by a person that has gone through the required training.

In addition to this, the material flow of the new packing area is going in a different direction than the current material flow, towards the shipping area. This means that when the orders have been packed, they are closer to the shipping area and the layout is hence estimated to further reduce the travel distance between the packing and shipping area. At the same time, the travel distance from the picking and packing area is increased, but with a significantly shorter distance than the savings in distance between packing and shipping.

6.3.2 Inventory

In the current packing area, orders are on average waiting for over an hour in the consolidation area after they have been consolidated and are ready to proceed to packing, waste 2.2. The consolidation area does not provide any visibility or make it clear which orders that are complete and which are still waiting for consolidation. If the pickers would place each order on the conveyor belt as soon as it has been completed, this would increase the visibility as the packers would know exactly which order to pack next: the one next in line on the conveyor belt.

Furthermore, the stop in material flow that results from when packages are waiting on trolleys to be transported to a shipping pallet, waste 2.3, is eliminated through direct transportation by outgoing conveyors.

Waste 2.1 is mainly dependent on how fast the orders can be consolidated by the pickers. Although the number of orders waiting for consolidation cannot be affected by the packing team, the space such orders require will be less with a consolidation area in place.

6.3.3 Over Processing

A goods-to-man system, where orders are transported to the packer as opposed to the other way around, will eliminate the unnecessary step of determining which order to pack next from searching in the WMS system, waste 3.1. Similarly, waste 3.7 will also be eliminated. By reducing the number of storage bins in the system, waste 3.2 and 3.3 are reduced. Trolleys will not be necessary with the new layout and waste 3.8 is hence also eliminated.

6.3.4 Unnecessary Motion

One of the pitfalls in packing station design that Gooley (2010) identified was to not design the packing station with the worker in mind. Seeing this, height-adjusted tables should be in place in every work station. The current tables can be height-adjusted, but the printer underneath the table is limiting this feature, resulting in poor ergonomics for shorter staff members. To resolve this, either new tables should be installed, or the printer should be positioned elsewhere.

In line with what Specter (2015) concludes, not all packing stations need to be designed in the exact same way. Stressful and repetitive motion injuries must be eliminated and new configurations for improved ergonomics should be implemented. A workstation for packing of BG requires additional space to not cause motion waste. Waste 5.3 can be eliminated by customizing the packing station for BG appropriately. Suggestions include installing new workbenches that have a separate sliding shelf that can be extended from the workbench if needed. By installing such shelves in every station, packers will not have to pack orders directly on the floor or on trolleys, waste 5.1, due to a lack of space on the workbench. Neither do they then need to lift and carry a heavy package over to the workbench for it to be weighed on the scale. Instead, the package can just slide from the extending shelf horizontally to the scale, without any vertical lifting. Waste 5.2 is also eliminated by installing the outgoing conveyor system. Since a lot of unnecessary traveling will be eliminated with the new layout, requiring less movement around each work cell, waste 5.4 is also reduced.

6.3.5 Correction of Mistakes

Since the new layout involves that the current flow racks will be removed and new, shorter, racks installed, waste 6.9 is eliminated. The decrease in the average packing time, from 5,13 minutes to 2,3 minutes, is also believed to eliminate waste 6.10 as the experienced workload will decrease along with a more efficient packing process.

6.4 Cost-Benefit Analysis

6.4.1 Conveyors and Racks

In section 6.2.3.1, it was concluded that about 12,72 meters of conveyor would be necessary for the inbound conveyor for flow A and B altogether in the new layout. Approximately the same distance would be needed for the reverse conveyor. The outbound section has also been assumed to be of a similar length for the cost estimations. As for flow C, the required inbound conveyor length is assumed to be longer, although there are many uncertainties in determining the most suitable length of it. In the illustration in Figure 49, section 6.2.8, the length of the inbound and outbound conveyors is adding up to about 9,4 meters. Considering the cost proposal of 3.500 SEK/meter, the total cost of conveyors would be roughly 166.000 (~(12,72*3 + 9,4)*3.500).

Single-deep racks represent the least expensive rack option and cost about 470 to 710 SEK per pallet position (Conner, 2018; King, 2011). Since the consolidation area is not measured in pallet position, it is estimated that about 11,61 pallet positions would be needed, see Table 27 for calculations. The cost estimations of installing new racks are found to be roughly 7.000 SEK (~590*11,61) if the average cost per pallet position is used to estimate the costs. No additional costs for additional shelving for BG orders are considered.

Table 27: Estimation of the number of pallet positions in consolidation area

Consolidation area	Width per level: 3,76 + 0,45 + 0,77 = 4,98 m Total shelving width: 4,98* 5 = 24,9 m Shelving area: 24,9 * 0,58 = *14,44 m^2*
Pallet size	1,22 m x 1,02 m = *1,24 m^2*
Number of pallet positions in consolidation area	*14,44 / 1,24 = 11,61 pallets*

These two cost components can then be put in comparison to the savings in time that can be directed elsewhere, as a result of a higher throughput in the packing process. The total cost of conveyors and racking adds up to 173.000 SEK. Implementation of the future-state packing process through a new design of the packing area layout would decrease the packing process time by 42 percent, and doing so would provide savings of 13,1 packing hours per day. This time should preferably be spent on more value-adding activities. The cost of an operator is approximated to 300 SEK/hour. The value of the investment could therefore be translated to the value of 13,1 packing hours, which is 3.930 SEK/day (300*13,1).

Considering the implementation costs and the benefits in terms of saved packing hours, the redesign would be profitable in less than two months (166.000/3.930 ≈ 42,2 days). For these calculations, the expected growth has not been considered. With increasing volumes, the absolute savings in packing hours would increase even further if the packing process were to be designed for improved efficiency. This speaks to making investments for improved efficiency to also be able to efficiently handle higher volumes.

6.4.2 Tape-Machine

From the performed time studies, it is estimated to take on average 7 seconds to seal a package. The cost of the tape-machine would be 45.000 SEK and the cost of an operator is approximated to 300 SEK/hour. For the investment to be profitable , it must save 150 operating hours (45.000/300), or 540.000 operating seconds. This implies that a minimum of 77.143 orders (540.000/7) must be packed before the investments would have a positive ROI. If six tape-machines are used, one for each packing station, this would occur when a total of 462.858 (77.143*6) orders have been packed, which would be within approximately 4,73 years (462.858/(8.151*12)) if no growth is taken into account. If a growth of 20 percent is considered, the future volumes would be higher, and the pay-back time would decrease to 3,94 years (462.858/(8.151*12*1,2)). Hence, the actual pay-back time is likely to be somewhere in between 3,94 and 4,73 years, depending on the growth rate in the next coming years. Even though the tape-machines could provide time savings, the considerably long pay-back time implies that it is not excepted that investing in them would be justified, and that this step should be performed manually. Tape-machines will therefore not be included as a part of the recommendation for a new layout proposal.

Chapter 7

Conclusions

This final chapter contains the conclusions of this master thesis. First, the research questions will be answered. Then the contributions of the thesis will be discussed and suggestions for future research topics are provided. Lastly, the limitations of the research are noted.

7.1 Answering the Research Questions

The purpose of the master thesis is to identify waste and the corresponding root causes in the existing packing processes at AL DC Tumba and investigate how warehouse automation could be used for waste removal in developing a new packing area layout. In the following sections, the conclusions to the two RQs of the study will be presented.

7.1.1 RQ1

From observations, interviews and data analysis, a total of 40 wastes have been identified, of which 21 of them are directly or indirectly affected by the design of the packing area layout and presented in Table 28.

Table 28: The identified wastes within the packing process that are affected by the design of the current packing area layout

WASTE CATEGORY	WASTE
Traveling	1.1 Traveling to the consolidation area to collect an order to pack 1.2 Traveling across multiple packing stations to collect an order to pack 1.3 Traveling across the aisle to collect a suitable carton box 1.4 Traveling within the packing area or across the aisle to place a package 1.5 Traveling within the packing area to find a trolley to place the package onto 1.6 Traveling to refill carton boxes and bubble wrap at the packing station 1.7 Traveling to the consolidation area to return empty storage bins 1.8 Traveling to the DG lane to collect orders to pack and to collect DG labels at work station 13
Inventory	2.2 Consolidation area stores completed orders waiting to be packed 2.3 Packages stored onto trolleys for further transport to shipping pallets
Over processing	3.1 Manually determining which order to pack next 3.2 Gathering multiple storage bins to collect an order instead of one 3.3 Moving around the storage bins, sorting and consolidating the articles into one or fewer storage bins for orders that are yet not fully consolidated 3.7 Searching for a NC-order that has an earlier departure time than the NC-orders placed in front of it
Unnecessary motion	5.1 Preparing and packing goods directly on the floor 5.2 Carrying relatively heavy packages across the aisle 5.3 Ergonomic issues at packing stations 5 and 6, where BG are packed 5.4 Almost running into other workers at the packing station

Correction of mistakes	6.9 Storage bins that are not collected as they are stuck further back in the gravity flow racks, not visible to the packers 6.10 Increased number of human errors as a result of stress	

The causes of the wastes have been identified through the use of the 5Ws tool. Four main causes are identified: (1) a man-to-goods system is being used which increases the need for travel, (2) the layout does not provide a visual workflow, (3) the consolidation area and system are inappropriately designed, and (4) the packing station design causes poor ergonomics when packing bulkier and larger customer orders. Each waste has been mapped to either one or multiple causes, as found in Table 29.

Table 29: Mapping of how the current layout causes waste

WASTE	***CAUSE***
1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 2.2, 2.3, 3.1, 3.8, 5.2, 5.4	A man-to-goods system is being used which is increasing the need for travel
2.2, 3.1, 3.7	The layout does not provide a visual workflow
2.2, 3.1, 3.2, 3.3, 6.9	The consolidation area and system are inappropriately designed
5.1, 5.3	The packing station design causes poor ergonomics when packing bulkier customer orders or orders of larger sizes

7.1.2 RQ2

From the conducted analysis, a suggestion for a proposal for a new packing area layout has been developed. Four different proposals of how the layout can be configured have been provided. The proposals for the layout are based on a goods-to-man system that suggests dividing the packing process into three, as opposed to the current two, different flows; here referred to as flow A, B and C. The flows are distinguished by the physical volume and bulkiness of the orders included. Flow A represents 77 percent of customer orders and thus constitute the largest flow with regards to the number of orders. Flow B stands for 9 percent and flow C a total of 14 percent. As an order in any of the flows has been consolidated, it is placed on a conveyor by the picker, and transported to a packing station, where the order will be packed. After an order has been packed, the package is placed on a second conveyor and transported to the end of it. From there, it is placed on its associated shipping pallet.

Consolidation Area

Flow A-orders make up the smaller orders with regards to the physical volume, and are consolidated in a smaller storage bin with the dimensions 37x41 cm. Flow B-orders make up the medium-sized orders and are consolidated in a larger storage bin with the dimensions 41x58 cm. From the analysis, the dimensions of the consolidation area can be summarized as in Table 30. To be able to stack more items in some of the storage bins and hence reduce the required number of storage bins, it is suggested to have one or two levels in the shelves used for consolidation that have a height of at least 30-40 cm for flow B, whereas the height for the majority of levels can remain at the current 22 cm or similar.

Table 30: Dimensions of the consolidation area

FLOW	NUMBER OF BINS	DIMENSIONS PER BIN	STACKING HEIGHT/ DEPTH	TOTAL WIDTH	TYPE
A	0,77 * 61 ≈ 47	37x41 cm	5 bins/ 1 bin	3,76 m	Single-deep racks
B	0,08 * 61 ≈ 5	41x58 cm	5 bins/ 1 bin	0,45 m	Single-deep racks
C	0,14 * 61 ≈ 9	37x41 cm, 41x58 cm	5 bins/ 1 bin	0,77 m	Shelves/ Single-deep racks

The recommended stack depth is one storage bin, and each bin is limited to one customer order only. However, if required, the orders can be stored within multiple storage bins at different locations within the consolidation area. For flow C, storage bins will only be used for some of the smaller items, as the bulkiness of the larger goods included in these orders generally makes it difficult to store such goods in anything apart from on shelves such as the ones that are currently being used. Apart from this, additional space should be added to the consolidation area for flow A and B to store partial orders from flow C that are not considered as bulky. This is unavoidable as the picker that arrives to the consolidation area with the first suffix of the order would not for certain know how much space that the order will require for consolidation, since it is dependent upon the dimensions of other SKUs that are yet unknown to the picker. Additional space could be added to the consolidation area as the same issue could be faced by pickers that are consolidating flow A- and B-orders.

Packers and Packing Stations

If a growth of 20 percent is considered, it can be concluded that a minimum of three packing stations will be necessary for the packing of flow A and B altogether. Resulting from the percentages that each flow represents, two packers would pack orders from flow A and one packer from flow B. However, this can be somewhat flexible, and depends on the workload throughout any day. The two flows mainly differ with regards to the storage bin size that they are stored into during consolidation, and it is therefore only of importance that consolidation area B should be located closer to the packing station that would be operating flow B, whereas flow A can be packed at the remaining packing stations. Further analysis included a worst-case scenario with a high proportion of flow A-orders, which generally have a longer packing time per order line. To hold the capacity for a 20 percent growth during a day with a worst-case order size distribution, four packing stations would be required for flow A and B, mainly as one additional packing stations would be needed to handle the higher proportion of flow A-orders.

The packing of BG orders, included in flow C, differs as BG will generally have a higher need for special handling in the packing process. Considering a growth of 20 percent, analysis shows that one packing station is sufficient to handle the volumes in flow C. However, to hold the capacity for a 20 percent growth during a day with worst-case order size distribution, two packing stations would be required to be implemented to handle the volumes in flow C.

Conveyors
To decrease the cost of conveyors, gravitating conveyors should preferably be used. The minimum length of the inbound conveyors is estimated by considering the maximum number of accumulated orders that have been consolidated and proceeded to the next step of packing the order. The results show that a minimum of 3,18 meters would be needed for each conveyor section for flow A and B. For the conveyor serving flow C, the deviations and bulkiness of product dimensions call for additional conveyor space. The conveyor is made as long as possible, adding up to about 9,4 meters for the inbound and outbound conveyor altogether. Another alternative for flow C is also to not have an inbound conveyor and only use an outbound conveyor for sealed packages.

Packing Station Design
To decrease motion waste when packing BG, it is recommended to install sliding shelves to a new workbench. In addition to this, the printer should be placed elsewhere to allow shorter packers to achieve improved ergonomics.

Packing of DG
Traveling waste can be eliminated by operating a packing station that is equipped with everything necessary for the packing of DG. One employee that has gone through the required training could be assigned the responsibility of DG and operate this packing station for each day.

Storage of Materials
Traveling waste whenever refilling of bubble wrap and some of the carton sizes are reduced as storage of these materials is positioned in a more convenient location.

Staging
Traveling waste within the dispatch function is minimized by staging the shipping pallets closer to the shipping area. This would minimize travel within the packing process as well as the shipping process, ultimately reducing waste.

Results from Implementing the Layout Proposal
The proposal will reduce or eliminate each of the 21 identified wastes that are caused by the current packing area layout. Implementation of the future-state packing process through a new design of the packing area layout would decrease the packing process time by 42 percent, and doing so would provide savings of 13,1 packing hours per day. This time should preferably be spent on more value-adding activities. A cost-benefit analysis shows that the implementation costs are repaid within two months, as a result of the savings in the daily required packing hours. Moreover, the savings in time could be translated into savings in future labor costs as future hires might not be required along with volume growth.

7.2 Contribution of Thesis

7.2.1 Contribution to Theory

So far, research on Lean logistics has been focusing on other logistics functions such as transportation and purchasing and not on warehouse operations (Abushaikha, 2018). As also been mentioned, the warehousing research has so far been focusing on the picking process, whereas there is limited research on the packing process. The thesis hopes to emphasize the importance of resolving bottlenecks, and to not only limit the focus to the most labor-intensive process within the warehouse. As such, the thesis aspires to contribute to research on the packing process, which was considered to be the main bottleneck within the warehouse at the case company.

Although the recommendations are specific for the case company, the used approach and results from the study could be utilized when redesigning the packing process for other cases. In this way, the thesis also contributes to theory by showing relevant factors that should be considered in a redesign of a layout of a packing area, something that differs from designing a completely new warehouse.

The three-step framework that was applied had been developed from previous research. However, the prior work was limited as it lacked a real case study (Mustafa et al., 2013). Cagliano et al. (2018) presented the application of the framework to a warehouse in the automotive industry. A validation campaign is currently pursued, to assess the applicability and accuracy of the framework in industries that need to adapt quickly to demand variations. By using the proposed framework and practically implementing it, the thesis has enhanced the academic literature of Lean warehousing and proven the framework's usefulness. For the purpose of the study, the framework was applied for a spare parts warehouse, which to the best of knowledge have not been studied before.

7.2.2 Contribution to Practice

The case company benefits from the thesis as it provides an exhaustive overview of all wastes that could be identified from multiple days of observations of the packing process, hence bringing underlying issues within it to the surface. The main aspiration is to contribute to the case company by providing a solution for the redesign of the packing area layout. The case company can then decide to implement it, or individual parts of it, as the redesign will take place.

The thesis has also contributed by other means. Through the numerous data analysis that has been carried out, the case company has also been provided with an overview of the DCs flows, with regards to both size and timing, which can be helpful to the company during analysis for other purposes. DMAIC stands for Define, Measure, Analyze, Implement and Control. The second step in the DMAIC methodology is to measure the process, and a step that was carried out as the first time study was performed, after the scope had been defined in the initial step (Phase 1). However, the complete methodology was not applicable for the thesis and after the analysis step, the two remaining steps were not included in the scope of the thesis. Nonetheless, when the layout redesign has been implemented in the fourth step, the new process time can be compared to the results from this study, and be used to measure the impact of changes in the last and final step. Regardless of whether the proposal resulted from this thesis is being followed or not, the time study in itself thus provides value to the case company.

7.3 Future Research

7.3.1 Suggestions for Future Research

As the literature review was conducted, it was evident that there is a gap in research on how to design an efficient packing process and on layout design for a packing area. To bridge this gap, it is suggested to explore how the packing process and layout have been designed in different warehouses that are handling different product characteristics through for example a multiple-case study.

7.3.2 Suggestions for Future Research within the Case Company

Due to the time span and scope of the thesis, there exists room for further research. One suggestion for future research for the case company is to investigate the potential benefits of using mobile packing stations. This could, for example, be implemented for NC orders from any of the zones E1-E6. Items from these zones are currently being picked in picking carts, but there is potential for increased efficiency and a decrease of double handling if NC orders could be directly picked into the carton box on the go. Since the items that are picked from any of these zones represent a smaller volume, a greater number of the smaller carton boxes, such as T-03, T-04 and T05, could be placed on the cart for improved efficiency. The waste of handling storage bins would then be eliminated.

One aspect that currently limits the available automation solutions that could be explored in this thesis is the WMS, which is outdated and cannot be changed by AL DC Tumba. However, there are plans on a corporate level to invest in a new ERP system. When the ERP system is updated and a new WMS is in place, other solutions could be explored. For example, A/SS to packing or shipping lanes, or both, could be leveraged as soon as the WMS has been updated. The weighing of packages is also something that could be considered, if the integration of this with the WMS is feasible.

7.4 Limitations

The average packing time that was estimated from the time studies are based on the sample data and affected by the order size distribution of the chosen samples, as illustrated in Figure 27, and discussed in section 4.2.2.3. As this will vary from day to day, the order size distribution will not align perfectly with the order size distribution from the conducted time study. However, to explore the dependency of the order size distribution, a sensitivity analysis was conducted as to how variations in the distribution would affect the resulting number of packers and packing stations, and recommendations were provided accordingly.

As the DC generally do not experience any seasonality, only ERP data from one month was studied in the analysis. However, this provides a limitation of the study since there is a possibility that other flow patterns could have resulted in other conclusions if another, or a longer, time period would have been analyzed.

However, as a growth of 20 percent is also being considered, this assures that the recommendations on packing area design still hold and that the layout proposal will be able to handle the current volumes.

To model random variations and analyze the warehouse process in a virtual setting, warehouse simulation can be leveraged. In order to do so, incredible amounts of data would be required as input into the model, which is why simulation was not performed as a part of the thesis. This provides a limitation as the layout proposal cannot be verified to assure that no bottlenecks will be caused as the proposal is implemented.

Another limitation is the difficulty of predicting physical dimensions of orders more precisely. By mapping the use of carton boxes, the size of each flow could be estimated. But clearly it is only an estimate and the variations are difficult to predict from the available data. To arrive at a more precise number, data on the physical dimensions of individual SKUs would be necessary. If product cubing data would be available, it would not only be leveraged when choosing a suitable carton box but could also be used to determine which storage bin an order should be consolidated in. Similarly, it is difficult to predict the impact that deviations in the percentages that flow A, B and C generally represent would have. The percentages that for example were used as the consolidation area was analyzed are based on averages, and will deviate daily. It is also difficult to predict how well the procedures would be followed, as it depends on which suffix that is consolidated first. Such uncertainties should be considered, perhaps in a warehouse simulation model, to assure that the new layout can handle these uncertainties.

The performance of the picking process is affecting the performance of the packing process in many ways. In the analysis, data on timestamps were analyzed in order to ascertain how the packing area would need to be designed to handle both the volume of the flows, as well as the timing of them. Whereas the volume is determined by the customers of AL DC Tumba and not within the control of the DC, the time duration that an order is waiting for consolidation and the timing of when orders are being consolidated and available for packing are dependent on the picking process in the DC. In the analysis, the timestamps from the day with the highest throughputs, 2019-05-07, were considered as given parameters. However, this is not the actual case, and future changes in the picking process, resulting in improvements in picking performance, could imply that other recommendations should be provided. For example, if pickers can complete the order consolidation faster, the consolidation area should preferably be smaller in size to avoid usage of excessive space. If orders could be released for packing in a more continuous flow, the conveyors should be even shorter for the same reasons and a lower number of packing stations recommended. If the flows would vary less throughout the day, four or five packing stations might be sufficient as the stations would receive orders continuously throughout the day so that the packers that would be stationed by them could also be packing continuously. Although it is of the author's belief that the influence that the picking process has on the packing process is of high importance, the outcome of such factors have been difficult to predict in the study, and was therefore not considered.

As for the cost-benefit analysis, the numbers are only serving as pointers. The cost estimates have assumed that materials, freight, installation and project management services are included (Canner, 2018), but costs resulting from down-time during the implementation of the packing area is an example of a cost that is not taken into consideration. Moreover, only the benefit of a decrease in the packing time is included in the cost-benefit analysis, whereas the cost of a potential increase in picking time is not. This increase could potentially arise as the recommendations imply that the pickers will be required to collect the storage bin every time an order has completed its consolidation and move it to the inbound conveyor. This is an additional step that is not required with the current layout. Nonetheless, the cost estimations are adequate to get a rough sense of the benefits of investing in a new packing area layout as opposed to the costs of it. Considering such a short pay-back time as 42 operating days, the result also shows that even if the actual costs of implementation would increase, such deviations would not change the fact that by redesigning the packing area, great benefits could be achieved for relatively low costs.

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Appendix A: Warehouse Layout

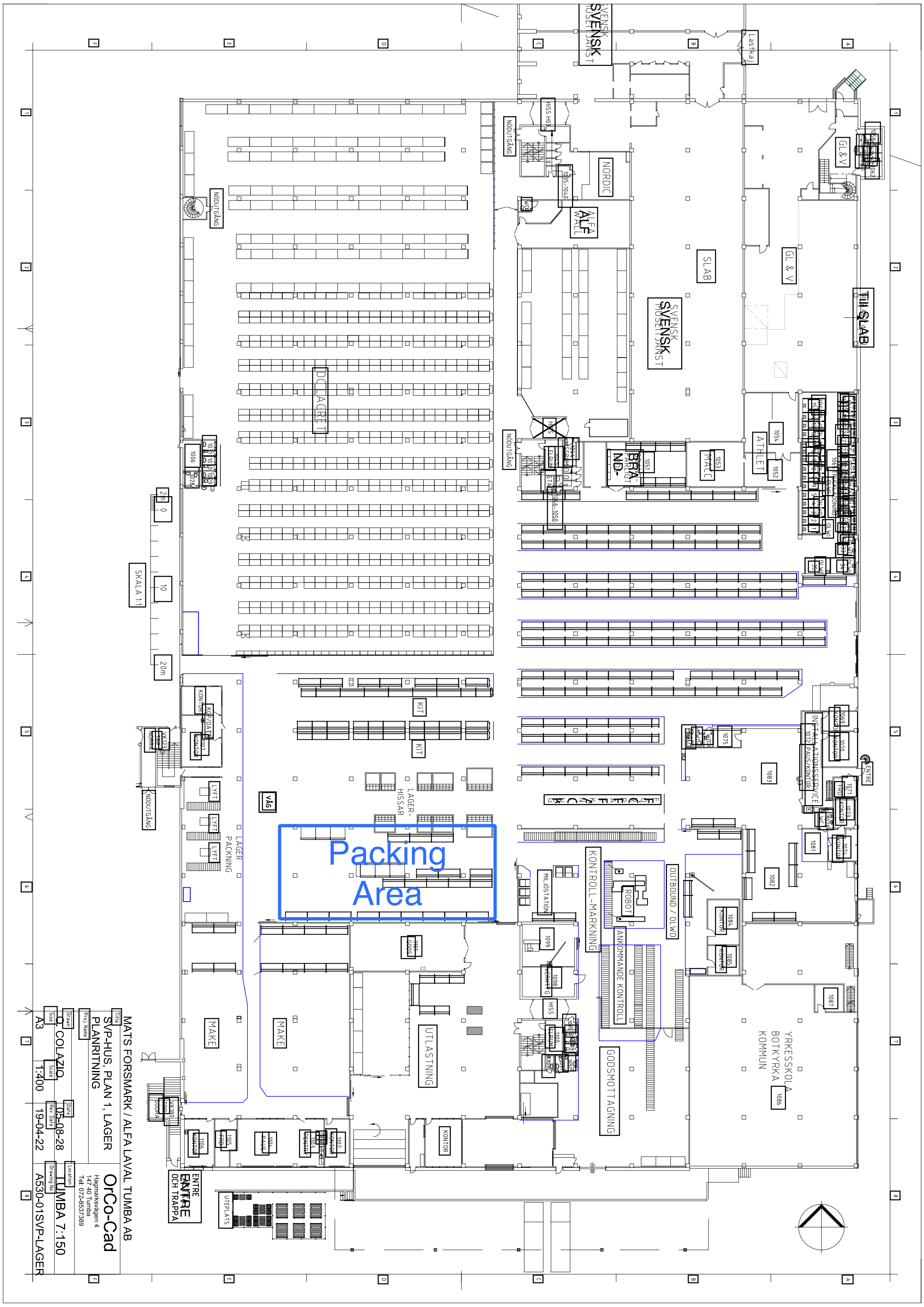

Figure A1: Layout of AL DC Tumba

Appendix B: VSM Icons and Example

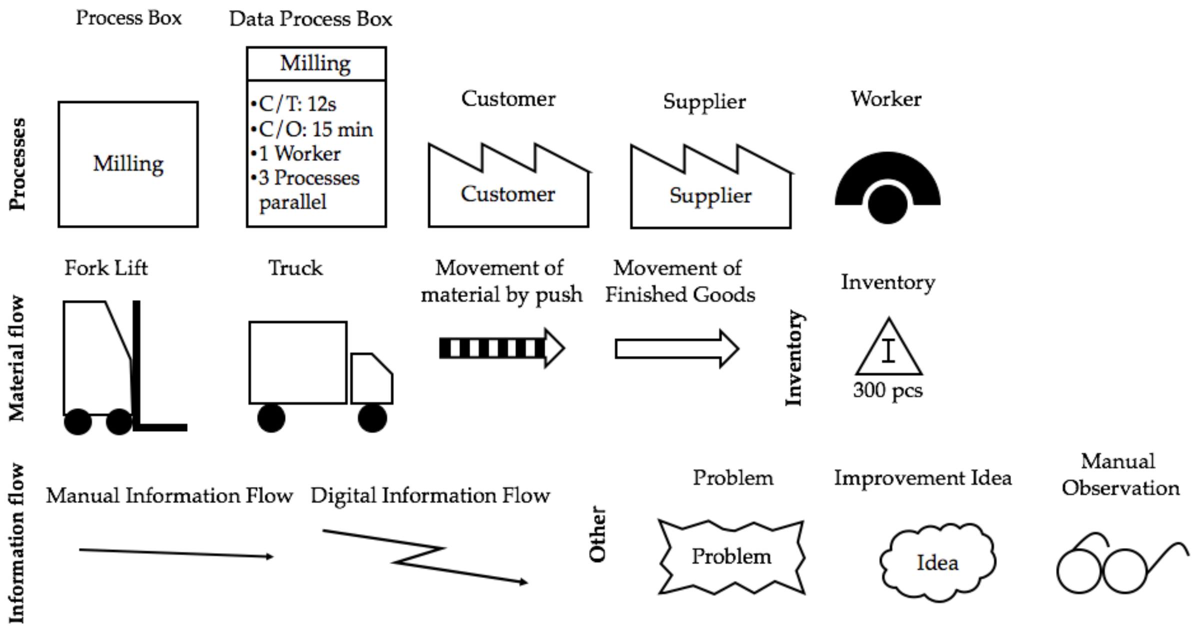

Figure A2: Examples of some icons used for VSM (Rother & Shook, 1999; Roser, 2015)

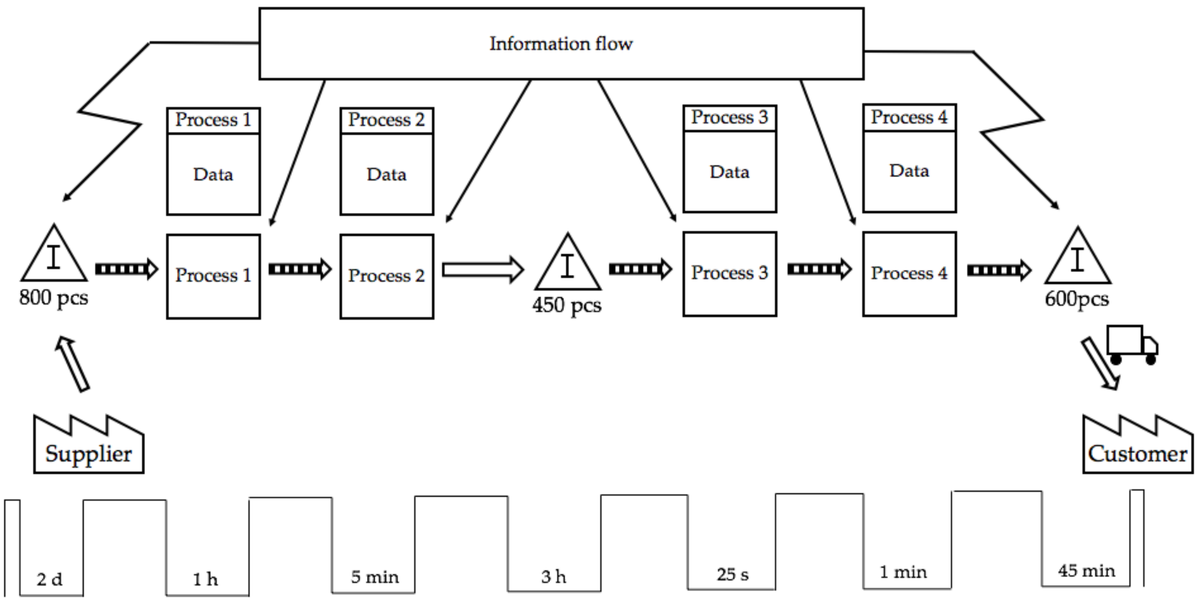

Figure A3: An example of a current-state map (Adapted from Roother & Shook, 1999)

Appendix C: Waste Analysis

C.1 5Ws

The complete application of the 5Ws tool is presented in Table A1.

Table A1: 5Ws application for the identified wastes

WHAT	WHEN	WHERE	WHY	WHO
1.1	When collecting a new order to pack	Between the packing station and consolidation area	A man-to-goods system is being used, where the packer needs to walk several steps to collect the orders	Packer staff
1.2	When collecting a new order to pack	Within the packing area, across other packing stations	A man-to-goods system is being used. The packing area is large and orders are sometimes placed unevenly distributed over the consolidation area	Picker and packer staff
1.3	When a carton box of some (of the sizes) is collected for packaging	Across the aisle from the packing station	Due to limited space, larger carton boxes are stored far away from each packing station	Packer staff
1.4	When an order has been packed	Across the aisle from the packing station	The shipping pallets are located far from the packing stations	Packer staff
1.5	When an order has been packed	In the packing area	The packing area is crowded with trolleys and some are standing farther away from a packing station than others	Packer staff
1.6	In between packing two orders or during the process of packing an order	Between the packing station and the storage location of bubble wrap and smaller carton box sizes	The bubble wrap and carton boxes are stored far away from the majority of packing stations	Packer staff
1.7	Between packing two orders or during the process of packing an order	Between the packing station and the consolidation area	One or multiple storage bins are used for order consolidation	Packer staff
1.8	When packing DG	From other packing stations to the DG lane and the packing station designated for packing DG	DG are packed by the packers that have gone through the required training, which can be packing goods in different work stations depending on which day. The DG flow is not large enough to justify having a packer completely dedicated to only DG	Packer staff with the required training to pack DG
2.1	When orders are yet waiting to be completed	Consolidation area	Due to the picking strategy and an outdated WMS, it sometimes takes a significantly longer time to complete orders that are picked from different zones and by different pickers	Picker and packer staff
2.2	When orders are waiting to be packed	Consolidation area	A result of a manual decision process for which order to pack next and a lack of visibility in the consolidation area. Moreover, packers will base the decision on which order to pack depending on the order deadline. Pickers will	Packer staff

			also pick after order deadline, but the SOP seems to not always be followed.	
2.3	When packages are waiting to be transported to a shipping pallet	On trolleys in the packing area	The trolleys are used to avoid heavy lifting and unnecessary traveling since packages sometimes need to be transported across the aisle to be placed at a shipping pallet	Packer staff
3.1	When determining which order to pack next	By the computer in the packing station	A result of the WMS and a man-to-goods system	Packer staff
3.2	When collecting the next order to pack	Consolidation area	Each picker will put each suffix in a separate storage bin. If an order is picked from several zones, the customer order will be consolidated in multiple storage bins. Also, the storage bins are not always big enough to fit all the order lines in a suffix, and multiple storage bins can be used for order lines picked from the same zone due to the dimensions of products	Picker and packer staff
3.3	Between packing two orders or during the process of packing an order	Consolidation area	There is sometimes an excessive amount of storage bins used to consolidate a customer order. Since it is more troublesome to gather multiple storage bins and take them to the packing station when the order is about to be packed, packers are removing some of them and sorting the order lines to fewer storage bins every now and then	Packer staff
3.4	When scanning an article	By the computer at the packing station	A result of the WMS and therefore not investigated further	Packer staff
3.5	When printing the shipping label and consignment-notes for a package that is going to be delivered by DHL Express	Packing station	The system has not been updated, and the consignment-notes are still being automatically printed	Packer staff
3.6	When adding protection material to a package	Packing station	The wrong carton box is sometimes chosen by the packer. Moreover, there is not always a suitable design of a box that can fit the order perfectly	Packer staff
3.7	When an order from the NC-lane is collected for packing	Consolidation area	NC-orders for a later departure have arrived to the consolidation area before NC-orders for an earlier departure. A result of either that the pickers are not picking the earlier deadlines before the later ones, or that some order batches take a shorter time to pick	Picker and packer staff
3.8	When forwarding a package directly to the shipping pallet	Packing area	Packers will sometimes walk directly over to the transport carriers shipping pallet, and sometimes put the package on a trolley and postpone the sorting and transportation of packages to shipping pallets. The trolleys are	Packer staff

			located across various locations in the packing area	
3.9	When printing customs invoices and shipping labels for some orders	Packing station	Some sales companies use a different computer system. The printing of customs invoices therefore needs to be carried out via this system	Packer staff, Management
3.10	When preparing and sealing carton boxes	Packing station	Some packers are unaware of the difference in requirements for different physical dimensions of customer orders	Packer staff
3.11	When performing quality assurance of a customer order	Packing station	Some pickers will affix the picking label on the transparent side of the plastic bags that hold some of the smaller articles, instead of putting in on the opposite, white site. This prolongs the time to count each item of an article and perform the quality checks when packing	Picker and packer staff
3.12	When the consignment-notes have been printed and are put into the package	Packing station	SOP not up to date, and a lack of information to packers that the procedures have changed	Packer staff, Outbound managers
3.13	When scanning each article in a customer order	Packing station	SOP not clearly communicated or being ignored by employees	Regards some of the packer staff
4.1	When printing consignment-notes and shipping label	Packing station	The printer is working slow and the packer does not take this time to perform other activities	Packer staff
4.2	When printing consignment-notes and shipping label	Packing station	IT system issues, therefore not investigated further	Packer staff and IT department
5.1	When packing an order in a carton box that is too big to fit on the workbench	Usually in packing stations 5 and 6, where BG are being packed, but also in other packing stations when larger items are being packed	The workbench is too small to be suitable to pack large and BG and cannot be customizable to such orders	Packer staff
5.2	When a package is transported from the packing station to the correct shipping pallet	Across the aisle from the packing station	A man-to-goods system is used and packers are not using the trolleys for transportation of packages	Packer staff
5.3	When packing BG	Packing stations 5 and 6	The packing stations are not designed to pack BG and goods therefore sometimes need to be packed directly on the floor or on the trolleys. However, the floor space is limited and such procedures require heavy lifting as the package still needs to be weighed on the scale that is positioned in the middle of the workbench	Packer staff at packing stations 5 and 6
5.4	When traveling around the packing station area	Especially prominent at packing stations 5 and 6	Limited space and a layout that requires traveling around the packing area	Packer staff
6.1	When checking the weight of a package	Packing station	Weights for different articles are incorrectly noted in the system. It can be a result of incorrect	Packer staff, IT department and suppliers

			information from suppliers, due to a large number of gaskets etc.	
6.2	When performing quality assurance	Packing station	Human errors	Picker and packer staff
6.3	When performing quality assurance	Packing station	Human errors	Picker and packer staff
6.4	When packing a customer order that includes a packed item that needs to be repacked	Packing station	Suppliers sometimes pack goods in containers that are not protective enough when the item is later shipped in its final shipping container	Packer staff and suppliers
6.5	When packing an order	Packing station	Decisions about which carton box to pack in is based on the packers' experience	Packer staff
6.6	When handing over picked goods to the consolidation area	Consolidation area	A result of human error. It can, for example, happen when a customer delivery is divided into several orders and the picker accidentally check the delivery number instead of the order number	Picker and packer staff
6.7	When handling metal goods	Consolidation area	Human error or lack of knowledge about SOP	Picker and packer staff
6.8	When packing and sealing a package	Packing station	A result of human error. The possibility of this to occur is higher when the SOP is not followed and packers will take out each article from the storage bins, and put them directly onto the workbench, see waste 6.10. As a result of this, the packer could accidentally miss putting every article in the carton box, or the article could accidentally get dropped onto the floor	Packer staff
6.9	When collecting a customer order	Consolidation area	Due to the chosen storage equipment	Picker and packer staff
6.10	Usually the afternoons, when the workload results in increased stress levels	Packing process	A result of the higher workload in the afternoons, which is forcing the packers to work faster and hence results in more human errors	Packer staff, Outbound managers

Faster-than-necessary pace is being excluded from the study. Regarding the eight waste, underutilization of people's skills and expertise, no wastes could be found. Contrary, AL DC Tumba seems to utilize their employees' skills to a high extent. Employees are encouraged to put up notes on the whiteboard where they can anonymously, or non-anonymously if preferred, provide their opinions on areas to improve and give their ideas and suggestions. Once a week, so-called improvement meetings are arranged. If the issue cannot be resolved directly, a PRP is developed, following the DMAIC methodology. The SOP is updated continuously.

C.2 5S

The complete application of the 5S tool is presented in Table A2. Due to the nature of the identified wastes, not all S-terms in the 5S-tool are relevant for all of them. Therefore, such are marked as non-applicable and not further discussed.

Table A2: 5S application for the identified wastes

WASTE	SORT	SET	SHINE	STANDARDIZE	SUSTAIN
1.1	Eliminate unnecessary traveling	Implement a goods-to-man system	N/A	Standardize new practices with a new layout	Follow new practices
1.2	Eliminate unnecessary traveling	Implement a goods-to-man system. Streamline flow, so that each packer is only packing from one lane	N/A	Standardize new practices with a new layout, assuring that each packer is only operating within its packing station	Follow new practices
1.3	Eliminate unnecessary traveling	Place all carton boxes closer to the packing station, based on FOM	N/A	Standardize new practices with a new layout	Monitor FOM and update storage locations if major changes can be observed
1.4	Eliminate unnecessary traveling	Install a conveyor system to eliminate travel	N/A	Standardize new practices with a new layout	Follow new practices
1.5	Eliminate unnecessary traveling	Install a conveyor system to eliminate travel and the need to use trolleys for transportation of packages	Clean and free up space by removing the use of trolleys	Standardize new practices with a new layout	Follow new practices
1.6	Eliminate unnecessary traveling	Place storage of carton boxes and bubble wrap closer to the packing station or have someone else be responsible for refilling such materials	Assign storage space and put up clear labels. Make sure excessive material is removed from aisles and that items with a low FOM are removed from the storage space	Standardize new practices and determine responsibilities for the refilling of packing material	Follow new practices
1.7	Eliminate unnecessary traveling	Install a reverse conveyor system that can return empty storage bins back to the consolidation area to eliminate travel	Reduce the number of storage bins in the system	Standardize new practices with a new layout	Follow new practices. Conduct periodic checks/ audits to make sure all storage bins are

					returned in a way which eliminates unnecessary travel
1.8	Eliminate unnecessary traveling	Assign a person who is responsible for packing DG during a particular day to a work station that contains all the necessary labels and other necessary equipment	N/A	Assign responsibilities	Follow new practices. Evaluate how new procedures are working
2.1	Reduce to the extent that is possible	Assure pickers follow SOP	N/A	SOP is already established	Make sure standards are being followed, conduct periodic checks/ audits
2.2	Eliminate the inventory	Implement a goods-to-man system where pickers will notify when an order is complete and can be packed	Free up space of storing ready consolidated orders. Design conveyor lanes that can fit all orders that are waiting to be packed	Standardize new practices with a new layout	Follow new practices
2.3	Eliminate the inventory	Install a conveyor system and eliminate the use of trolleys	Free up space by removing the use of trolleys	Standardize new practices with a new layout	Follow new practices
3.1	Eliminate the step of choosing which order to pack and create a more visual workflow	Implement a goods-to-man system where the packer does not take a decision regarding which order to pack next	N/A	Standardize new practices with a new layout	Follow new practices
3.2	Reduce the number of storage bins in the system	Consolidate orders in one single storage bin	Free up space as fewer storage bins are placed in the consolidation and packing area	Standardize new practices with a new layout	Follow new practices
3.3	Reduce the number of storage bins in the system	Consolidate orders in one single storage bin	Free up space and eliminate the need for sorting amongst storage bins and clean up the consolidation area from an excessive number of them	Standardize new practices with a new layout	Follow new practices
3.4	Not in scope				

3.5	Eliminate this step	Update the system	Remove the need for having to clean the packing stations from discarded paper notes	N/A	N/A
3.6	Assure that the appropriate carton box is chosen	Train staff in how to choose an appropriate box, encourage to use measuring tape if a packer is uncertain of choice, or automate the task	N/A	Standardize practices and provide training	Provide continuous training
3.7	Assure each customer order is packed as soon as it arrives for packing	Implement a goods-to-man system where each order is packed as soon as it has been consolidated. Implement fast-track lanes for NC orders	Create a more visual workflow	Standardize new practices with a new layout	Follow new practices
3.8	Eliminate the use of trolleys	Let conveyor systems perform the task of transporting packages to shipping pallets	Clean up the packing area from trolleys	Standardize new practices with a new layout	Follow new practices
3.9	Avoid using different computer systems for similar tasks across the company	N/A	N/A	Use a standardized computer system within the company	Follow new practices
3.10	Eliminate unnecessary, time-consuming, steps	N/A	N/A	Add which carton boxes that required to be stapled and which do not in the SOP	Follow new practices
3.11	Put the article label on the white side of the plastic bag	Assure pickers are putting the article label on the white side of the plastic bags and follow SOP	N/A	SOP is already established. Set up improvement meeting and make sure everyone is informed of why it is important	Make sure standards are being followed, conduct periodic checks/ audits
3.12	Eliminate the step of putting the consignment-note in the package	Make sure packers are debriefed	N/A	Update SOP	Make sure standards are being followed, conduct periodic checks/ audits
3.13	Remove unnecessary double handling and create procedures that reduce the risk of human errors	SOP has already been established, but seems to not always be followed by everyone	Keep the workbench clean by not spreading out items over the bench	Standardize practices	Make sure standards are being followed, conduct periodic checks/ audits

4.1	Eliminate unnecessary waiting	Encourage packers to perform other tasks while waiting	N/A	Set up improvement meeting to discuss suggestions of practices to avoid this waiting time	Conduct periodic checks/ audits
4.2	Not in scope				
5.1	Design work stations where all types of orders can be packed directly on the workbench	Install a separate table where larger orders will fit. Use tables that can be height-adjusted in all packing stations without hitting the printer underneath the bench	N/A	Standardize new practices with a new layout	Follow new practices
5.2	Eliminate carrying of heavy packages	Implement a conveyor system where the packers do not need to carry any heavy packages, nor transport them on trolleys	N/A	Standardize new practices with a new layout	Follow new practices
5.3	Differentiate packing station design depending on the goods that are being packed at the station	Create a workbench designed for packing BG that provides more space	Keep the floor clean by not packing goods directly on it	Standardize new practices with a new packing station design	Follow new practices
5.4	Eliminate unnecessary movement around the packing station	Increase space per packing station or reduce the need for walking in the packing area	N/A	Standardize new practices with a new layout and packing station design	Follow new practices
6.1	Decrease the portion of items that have an incorrectly noted weight in the ERP system	Notify suppliers when information on wrong weights has been received from them	N/A	N/A	Continue following already established procedures
6.2	Decrease the risk of human errors to the extent that it is possible	N/A	N/A	N/A	Continue following already established procedures
6.3	Decrease the risk of human errors to the extent that it is possible	N/A	N/A	N/A	Continue following already established procedures
6.4	Eliminate the step of repackaging items	Inform suppliers about high standards of package protection. Give incentives for them to pack individual pieces in packages that ensure better protection if this will be required when shipping from DC, to	If having to repackage a product, make sure the excessive material is thrown away directly	Standardize requirements for product packaging	Make sure standards are being followed

		remove double handling			
6.5	Assure the correct carton box is chosen from the beginning	Encourage packers to use measuring tape if they are uncertain about a choice. Provide proper training	If the prepared carton box is saved for later, place it somewhere where it is not standing in the way of the workflow	Standardize procedures	Provide continuous training and continue following procedures
6.6	Decrease the risk of human errors occurring in the sorting process	Mark and distinguish the order number from the delivery number more clearly on the picking label	N/A	N/A	Continue following already established procedures
6.7	Reduce mistakes made due to unawareness about SOP	Debrief pickers of guidelines	N/A	N/A	Make sure standards are communicated and being followed
6.8	Make sure no items in an order are lost in the packing process to decrease the risk of errors or double handing	Assure that packers pack articles from storage bin directly into the shipping box	Clear workbench from everything that is unnecessary. Put necessary things on shelves, to prevent other things from hiding articles that are placed on the workbench	Update SOP	Make sure standards are being followed, conduct periodic checks/ audits
6.9	Improve visibility in the consolidation area	Remove flow racks and install racks with a lower depth, containing a lower number of storage bins per order	Create a new layout for consolidation area	Standardize new practices with a new layout	Follow new practices
6.10	Increase process throughput	Design a packing process which eliminates other wastes for reduced throughput times. A reduced throughput time by a more efficient packing process design will ultimately lead to a less stressful work pace during peak hours	Assure the area is cleaned before the peak hours in the afternoon	N/A	N/A

Appendix D: Layout Proposal

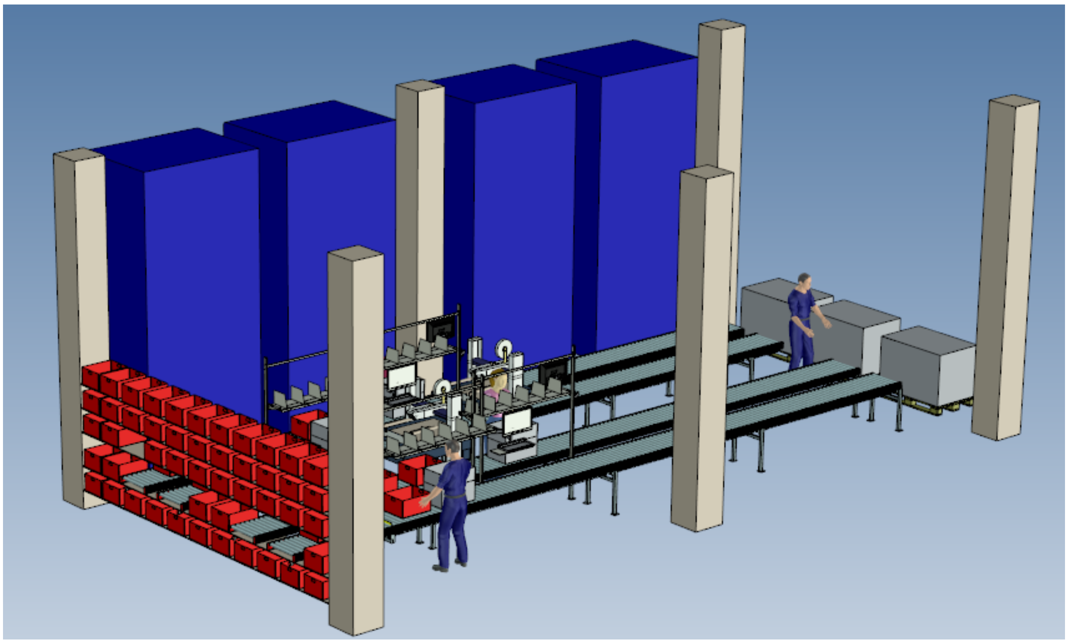

Figure A4: First draft of a layout proposal for the packing area

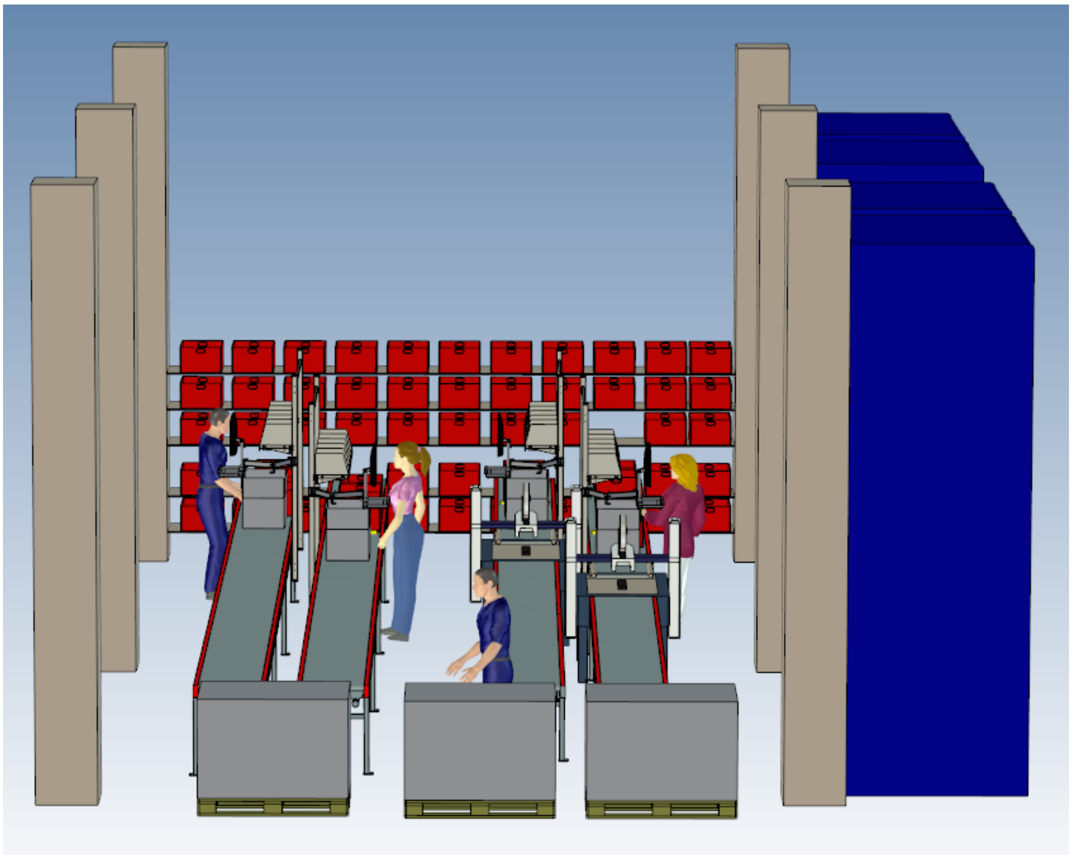

Figure A5: First draft of a layout proposal for the packing area

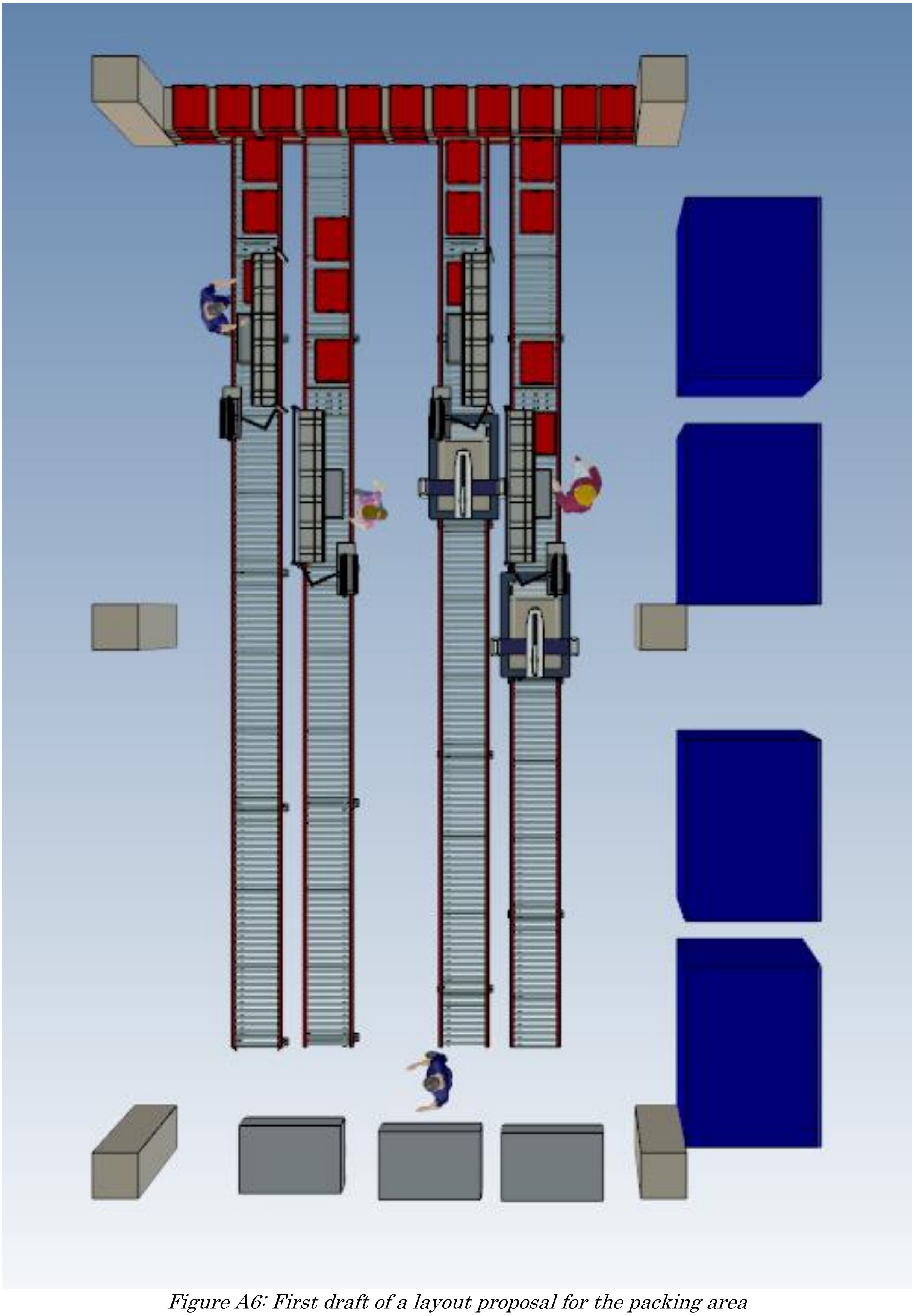

Figure A6: First draft of a layout proposal for the packing area

Appendix E: Interview Guide

The interview guide includes a list of main questions to the interviewees.

E.1 Workers at 'Outbound'

1. What are the main issues that you experience in your daily work? What problems do you encounter?
2. What problems can occur that would prolong the time to pack an order?
3. What do you do when an order is incorrect (incorrect article or quantity)?
4. How often do you have to correct mistakes made by the picker?
5. How does the stress level compare throughout the day?
6. Do you perform your work any different in the afternoon compared to the mornings?
7. How is DG packed? Which packing stations are dedicated to packing DG?
8. For which purposes are the goods weighted?
9. Why do packers sometimes change the consignment-notes after it has already been packed and put-away for the dispatch function to handle?
10. From your experience, is the space for each work station big enough to prevent workers from disturbing each other's work?
11. Are there any aspects of your daily work that you are dissatisfied with?
12. How can you impact your working environment?

E.2 Team Manager for 'Outbound'

1. Are there any aspects of the outbound processes that you consider problematic?
2. Which issues in the process do you consider to be especially important?
3. How do you deal with quality problems such as errors and damages?
4. Which hours/shifts do the employees in outbound work? How many operating hours were logged for 2019-05-27 and 2019-05-28?
5. How many employees are there and how many works in each department?
6. How is the schedule set for the number of people working in pick vs pack?
7. How many people have had the proper training to pack DG?
8. How does the material flow for DG differ?
9. How well are guidelines followed by the employees in outbound?
10. How many reports of inaccurate weights would you estimate to occur/ day?
11. How many internal errors in the picking process are noticed in the packing process per day? Who handles them?
12. How many zones are there in the picking area?
13. What different picking equipment do you have?
14. Why must the article be scanned twice when packing?
15. How often do you have improvement meetings? How does a PRP work?
16. Which carton boxes are applicable and can be used for packing CO light?