Using Lean Practices to Develop Improvement Suggestions for a Warehouse

A case study of a company in the perishables industry

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Acknowledgements

This thesis was conducted in the spring of 2021 as a final project of the Logistics and Supply Chain Management, Master Program at the Faculty of Engineering at Lund University. The thesis was conducted as a case study by a single author, at a cold storage warehouse facility of an actor in the dairy industry, Arla Foods in Jönköping.

I would like to take this opportunity to express my thanks to my supervisor Joakim Kembro, at the Division of Engineering Logistics, for providing valuable guidance and feedback during the entirety of the project. I also want to express my gratitude to the case company for making this thesis project possible. A special thanks go to my supervisor Jonas Granerås, Sami Kuutti, and Rickard Widegren for their insights and helpfulness during the project. Also, for providing bountiful information and data to help facilitate the process. Finally, I would like to thank friends and family for their ongoing support during the thesis process.

Lund, May 2021

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Abstract

Title – Using Lean Practices to Develop Improvement Suggestions for a Warehouse: A case study of a company in the perishables industry

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Purpose – The purpose of this thesis is to improve the turnover of goods at the most prominent locations in the warehouses' dispatch area, by identifying problem areas in the material flows that hinder the efficiency and provide remedy suggestions for these.

Design/Methodology – To fulfill the purpose a single in-depth case study is conducted with theory-building research purpose. The selected case company is a cold storage warehouse facility in Jönköping, Sweden, run by a multi-national organization in the perishables industry. A preliminary literature review is performed before making any empirical findings. Both qualitative and quantitative data are collected for the study. The qualitative data is gathered through the usage of interviews and observations, and the quantitative through the case company information systems data. A framework for analysis is used to guide the analysis that is focused on finding relationships and patterns between variables.

Findings – The findings of the thesis are a list of seven independent recommendations for the case company warehouse, that either generally improves the warehouse efficiency or reduces wastes in either of the three investigated material flow channels, which go under the names fine picking, tets, and crates. The recommendations induce more continuous processes with reduced touching points, reduced transportation distances, reducing the defects generated by the systems, improves workload balance and planning capability, and improves resource efficiency. Recommended is to implement more automation solutions, modify order-list generation algorithm, revise the current order-release structure, close two dispatch bays, implement solution for more flexible storage, install racks to increase height utilization, and invest in apt picking technology for one of the three main material flow channels. All recommendations are based on the analysis, that is derived from the literary and empirical findings of the study. A set of future recommendations and sensitivity aspects to consider is subsequently provided in the thesis.

Research limitations/implications – The single case study research approach limits the findings in generalizability to the specificity that is this case. There is also lacking perspectives and nuance limiting the findings, due to it being a single author. Primary theoretical implications are an exemplification that Lean, and value stream mapping can be applied in a warehousing context to generate efficiency improvements. It additionally supports pre-existing warehousing literature regarding e.g., the challenge in balancing the configurational elements, the significance of maintaining a holistic view, and the importance of setting and abiding by configurational goals.

Keywords – Warehousing, Material flow, Lean, Wastes, Value stream mapping, Case study

Paper type – Master's thesis

Abbreviations

AS/RS	Automatic Storage and Retrieval System
CMS	Commissioner
ERP	Enterprise Resource Planning
EUP	European Pallet
FEFO	First Expired First Out
FIFO	First In First Out
FTE	Full Time Employee
I/O	Input/Output
JIT	Just In Time
KPI	Key Performance Indicator
KPV	Fine Picking Rolling Cages (Swe. Kundplocksvagn)
LEs	Large Enterprises
LF	Low Frequency
LTA	Lost Time Accident
MTBD	Mean Time Between Departure
PDCA	Plan Do Check Act
QC	Quality Control
RO	Research Objective
SKU	Stock Keeping Unit
SMEs	Small and Medium-sized Enterprises
SOP	Standard Operating Procedures
S/R	Storage/Retrieval
TPS	Toyota Production System
VSM	Value Stream Mapping
WCS	Warehouse Control System
WES	Warehouse Execution System
WMS	Warehouse Management System

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1 Introduction

This section introduces the thesis by providing necessary background of the topic and case company. Problem formulation, purpose, research objectives, and focus and delimitations are featured to present the problem and define the scope of the thesis. Ending the section with presenting the outline and disposition of the thesis.

1.1 Background

Having efficient logistical operations is becoming significantly more crucial for organizations to remain competitive. It has become a necessity to manage the strain that the trends of shorter and shorter response times and increased product assortments put on (Rouwenhorst, et al., 2000; Martins, et al., 2020). Cutting logistics costs has historically been the driving competitive factor amongst organizations, but now they also must deliver on the customers' expectations of high performance on several other factors such as flexible delivery, high accessibility, return options, and more. Simultaneously, customers want shorter lead times, which puts pressure on retailers to reduce the total time required from order receipt to picking, packing, and shipping of the goods (Kembro and Norrman, 2020). A decisive factor for the overall efficiency and effectiveness of distribution networks is the operations of the nodes i.e., the warehouses (Rouwenhorst, et al., 2000).

Warehouses play an integral role in supply chain management and as a factor in the success rate of businesses (Baker and Canessa, 2009; Gu, Goetschalckx and McGinnis, 2007). It serves many purposes in an organization, but its main contribution is to help better match supply with the demand and to consolidate products (Bartholdi and Hackman, 2019; Baker and Canessa, 2009). To these more traditional roles, they are now also considered and has the potential to serve as a mean to achieve a multiple of company missions. Amongst these include acting as cross-docking points, value-adding services (e.g., kitting or labeling), reverse logistics, supporting the firm's customer service policies, and more (Baker and Canessa, 2009; de Koster, Le-Duc and Roodbergen, 2007). Warehousing operations do however also represent a significant amount of the total logistics cost in a supply chain, due to its operational and capital expenses (de Koster, Le-Duc and Roodbergen, 2007; Kembro, Danielsson and Smajli, 2017).

The warehousing activities concern the physical storage and handling of goods, and the processing of the information required for these (Gunasekaran, Marri and Menci, 1999). It considers the flow of goods, with flow meaning the general movement of a material or immaterial phenomenon, which for this context typically concerns the movement of *stock keeping units (SKUs)* throughout the warehouse (Mattsson and Jonsson, 2013). The aim of managing a warehouse should be to achieve a continuous flow of goods (Bartholdi and Hackman, 2019). Thus, making the concept of Lean a fitting option, which is an approach aimed at increasing the efficiency of the operations in a process. If a process is Lean, it has a minimal number of needless activities in its operations, no excess buffers, and overall efficient operations (Hallgren and Olhager, 2009; Abushaikha, Salhieh and Towers, 2018). It enhances value streams by reducing or eliminating all forms of waste and makes for a consistent smooth flow, through its tools geared to eliminate uncertainties and variations (Mattsson, 2012). However, while the principles of Lean have been widely adopted in the manufacturing sector, it has yet to see mainstream usage in warehouses and distribution centers (Bartholomew, 2008).

Companies always strive to improve the efficiency and effectiveness of their warehouse operations, but managing this is a challenging task (Kembro, Danielsson and Smajli, 2017; Faber, de Koster and Smidts, 2013). It is thus imperative that warehouses are designed to function cost-efficiently, due to its significance to the logistics costs and customer service levels, but also its inherent complexity (Baker and Canessa, 2009). Trying to obtain an optimum or near-optimum solution to the configuration is difficult since the options and possibilities are endless (Gunasekaran, Marri and Menci, 1999).

There is in general a sparse amount of literature on material-handling operations and management of storage systems, regardless of warehousing's critical role for businesses (Kembro and Norrman, 2020; van den Berg and Zijm, 1999). There has not been much written in academia about the systematic approach necessary to take for warehouse designers either, of which there is a clear need (Baker and Canessa, 2009; Rouwenhorst et al., 2000). With warehouses often viewed as a source of non-value-adding activities, there is improvement potential in applying the Lean practices, a concept which typically is applied to improve internal logistics operations in a company by reducing wastes. There have only been a few scholarly works about Lean warehousing and hence there exist gaps in the literature about it (Abushaikha, Salhieh and Towers, 2018). Which is something that more case studies and computational tools for warehouse design and operations might help bridge (Gu, Goetschalckx and McGinnis, 2010).

1.2 Case company

A case company is investigated for this study to gather more insight and knowledge into the field of warehousing theory. The selected company is the Danish registered dairy cooperative, Arla Foods. It is a farmer-owned democratic member organization, where all the dairy farmers have a voice, and all profits Arla makes goes back to them (Arla Foods, 2020). The current organization was formed by a merger of Swedish Arla ekonomisk förening and Danish MD Foods in 2000 (Arla Foods, 2020a). Today there are in total about 10300 owners in seven countries, these are Sweden, Denmark, Great Britain, Germany, Belgium, Luxembourg, and the Netherlands. All owners have a say in the cooperative democracy in Sweden there are 2600 owners (Arla Foods, 2020b). There are twelve dairies scattered across Sweden, to help supply the different regions of the country (Arla Foods, 2020c). Where the dairy in Jönköping, the selected case company, provides all southern parts of Sweden with supply of Arla branded milk, fil, and cream. It has been around since the middle of 1980 and has currently about 500 employees. The dairy produces and distributes over 100 different articles, with milk supplied primarily from the Arla farmers in the region of Småland (Arla Foods, 2020d). It has both a production unit and a warehouse facility, which manages the material handling and distribution of the dairy products, Figure 1 illustrates an overview of the Jönköping facility.

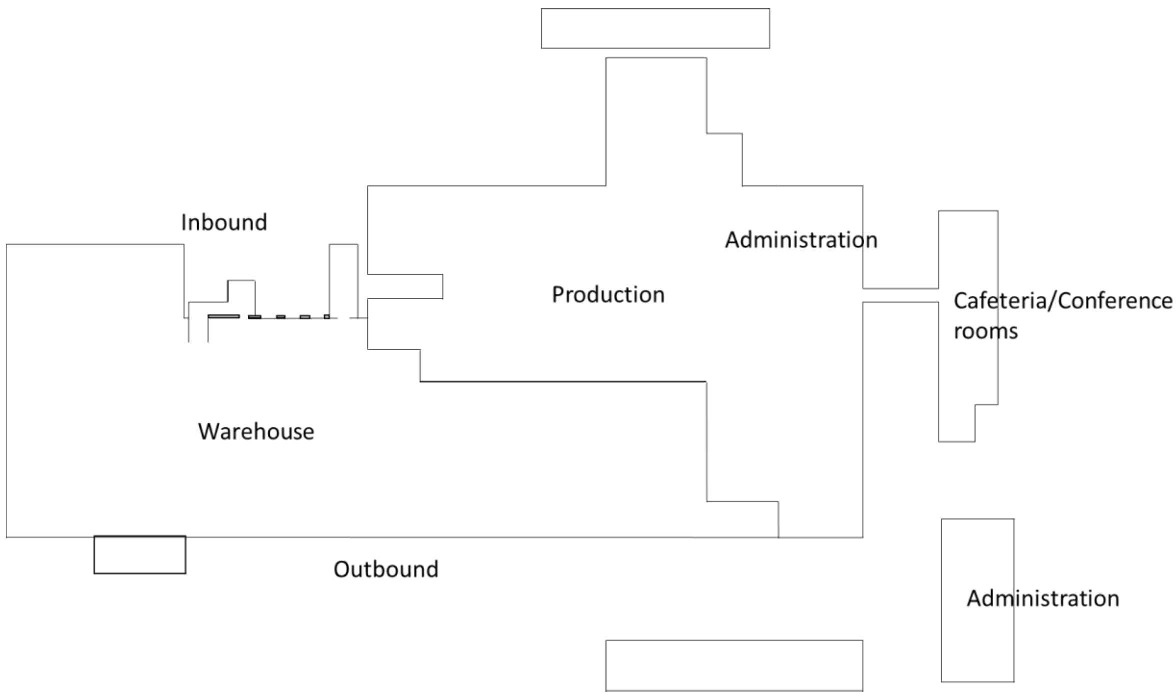


Figure 1. Illustration of the Jönköping facility

The warehouse in Jönköping receives both internally and externally produced products. Internally produced comes from the in-house production facility, and the externally produced comes mainly from other Arla subsidiaries, which is delivered to the warehouse who then acts as a distribution center and consolidates it with the internal products. The external goods have been outsourced to the Jönköping facility, to help manage the distribution to the end customers. Once the goods (both internal and external) have reached the inbound, they are mainly distributed into one of three flow channels, either to the *fine picking*, the rolling plane (*tets*) or, the *Multipickers* (*crates*). Crates is an almost fully automated process, whilst tets and fine picking have more manual processes in combination with automation solutions. The goods are diverted into these flows depending on where it comes from and its SKU. Products are picked based on customer order from these flows and transported to the dispatch area. Where they are loaded onto trucks to then be distributed to customers. The orders are pooled based on region for more efficient and environmentally friendly transportation of goods, calculated through a *warehouse management system (WMS)* to have as high a utilization rate as possible based on the orders.

1.3 Problem formulation

The efficiency of the material flows in the case company warehouse is the focal point for this thesis. As mentioned in the article by Rouwenhorst et al. (2000), efficient logistical operations, including warehousing operations, is critical for most businesses to thrive. At the case company, there is a distinction between the logical time and the actual time for the flow and throughput of goods at the warehouse. The larger designated bays at the dispatch must be optimized in terms of turnover of goods, to improve the overall throughput rate in the warehouse. Currently the poor *just-in-time (JIT)* of the material flows is locking up the most prominent locations at the dispatch. The management at the Arla Foods Jönköping warehousing unit suspects that a potential culprit of which are coordination issues between the three main material flow channels, with synchronization and synergistic errors generating inadequate timing and sequencing of goods. Other issues the management suspects being behind the inefficiencies are double actions, needless movement of goods, the human factor (for the flows containing manual entry), the time management between finished picked orders and when trucks should arrive for loading, the set WMS parameters, and/or the current convoluted flow configuration. All or some of these factors could be related to the root cause of the inefficiencies in the material flow, but the fact remains unknown at this point. The suggested causes are just conjectured by the management, which is why an investigation to identify the actual causes and their impact is necessary to identify and further suggest efficiency improvements to the warehouse operations at the case company's cold storage facility. Also, to fulfill the case company's aim of having the material flow and the value stream as JIT as possible in the warehouse.

1.4 Purpose and research objectives

With an overall goal of improving the turnover of goods at the most prominent locations in the warehouse's dispatch area, the purpose of this thesis become to identify efficiency improvements to the warehouse's material flows. To fulfill this purpose and provide recommendations for the case company, two research objectives (*RO1* and *RO2*) are formulated to help guide the study. These two research objectives are the following:

RO1: Identify problem areas that hinder the warehouse's efficiency

To make sustainable efficiency improvements a thorough as-is analysis of the warehouse configuration and its contextual factors is required. Understanding what factors influence the warehouse's performance is imperative to identify prominent problem areas. Because while it is known that there are areas in need of improvement in terms of efficiency, exactly where is not known. Thus, to improve the overall efficiency, the right areas must be targeted. To ensure this, a comprehensive understanding of the material flow channel's current state must be gathered. Once correct culprits have been identified, the improvement work can initiate. From which a future state configuration and recommended course of actions for the case company warehouse can be generated.

RO2: Develop remedy suggestions for the problem areas

Once a clear understanding of where the problem areas are and what factors influence the warehouse performance have been reached, potential remedies for the inefficiencies can start to take form. Root causes for the most impactful areas and factors will be analyzed, to make proper suggestions for a future state configuration and form the foundation for an implementation plan of potential changes. An analysis of the suggestions' potential can thus be made and discussed. Leading to a conclusion of the findings considering future research, and final recommendations for the case company warehouse on how to improve their efficiency.

1.5 Focus and delimitations

The targeted area for this thesis is the warehouse's configuration and operations, specifically the material flows. Immaterial flows are of secondary focus, which for instance include the movement of information between the WMS and other independent information systems in the warehouse such as the system managing the conveyors transporting items from the in-house production unit into the warehouse. Data gathering from both literature and the case company is concentrated on warehousing activities. The efficiency of the material flow is analyzed, using multiple tools and methods, some linked to the Lean philosophy. Efficiency here is referred to as "the ability to produce a desirable result without wastage", which for this instance regard the wastage of time and cost for the throughput of goods.

At the case company, the flow of goods inside the warehouse makes up the scope of the study. The flows moving towards the dispatch and loading docks and the time management of these being considered primarily. Where the three flows, with division based on their inbound procedure and the goods SKU, fine picking, tets, and crates are investigated. Most of the activities commonly associated with inbound and outbound are featured in the study. However, the loading and unloading of goods are not primarily regarded in the analysis. A schematic overview of the scope of the study is visualized in Figure 2.

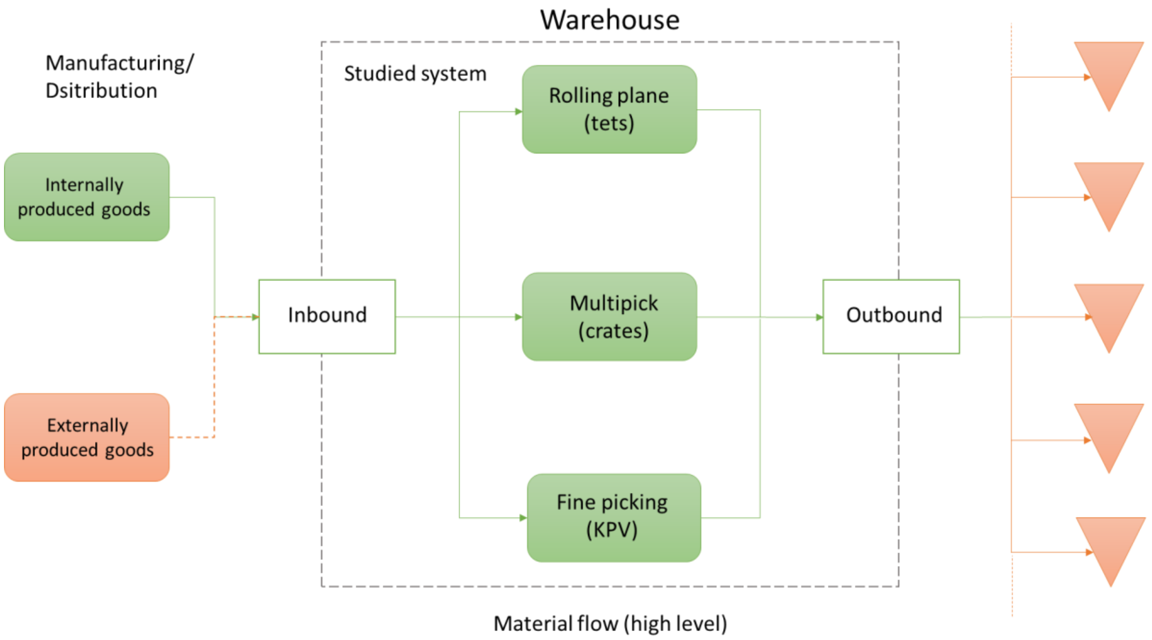


Figure 2. Illustration of the scope of the studied system

Depth in proposed solutions and identified inefficiencies is delimited, due to the thesis time limit of 20 weeks. Features such as a detailed implementation plan and thorough cost-benefit analyses of proposed improvements will, for the study to remain feasible, not be included in the scope. The focus lies on identifying problem areas and making improvement suggestions to the current state configuration at the case company warehouse, in terms of the material flow moving through the three main warehouse flow channels portraited in Figure 2.

1.6 Disposition

The outline of this thesis study constitutes seven sections. Starting with the introduction section, where the problem is formulated, and relevant background is provided. The research objectives outlining the study and the purpose are subsequently presented, ending with defining the scope of the study and the delimitations. The second section presents the methodology, which describes the research structure, how the study is conducted, how literature and data are gathered and analyzed, and finally how reliability and validity are ensured in the study. This is followed by the third section that presents the frame of reference, which provides relevant literature in the field of warehousing, Lean, and any adjacent topics of significance. Framework for analysis is presented at the end of the section to guide the analysis of the findings. The fourth section presents the empirical findings at the case company warehouse. These findings present the current state of the warehouse through different means and provide a summary of identified problems that hinders the warehouse's efficiency. The fifth section analyzes the findings from the empirical section with consideration to the literary findings to get satisfying remedy suggestions to the identified efficiency problems at the warehouse. Followed by the sixth section which presents the final recommendations to the case company warehouse through processing made suggestions in the analysis section. Subsequently, future projects and potential improvements are discussed. The seventh and last section presents the conclusion of the study. It summarizes the achieved research objectives and purpose of the study and discusses the theoretical applications of the findings. Ending with a discussion about future research.

2 Methodology

This section describes the methodology applied to achieve the purpose and research objectives of the thesis. The research strategy and structure describing the approach and design used for the study are presented first. Followed by a description of how and what data is gathered, and how it is subsequently analyzed to provide answers to the research objectives. The section ends with a description of how the validity and reliability of the data analysis are ensured in the study.

2.1 Research strategy

Choosing a fitting research strategy is important to fulfill the purpose of the study. There are many to choose from, including but not limited to: survey, case study, simulation, and mathematical modeling (Forza, 2002), also action research and design science research. Deemed apt for this thesis project, is the case study research methodology, which per the definition given by Meredith (1998), is an approach that uses multiple tools and methods for gathering data from several entities by a direct observer(s) in a single natural setting. Contextual and temporal aspects are thus taken into consideration when studying the contemporary phenomenon, without resorting to any manipulation or experimental controls. The tools and methods applicable for this strategy include both quantitative and qualitative approaches (Meredith, 1998), all of which are fitting for the context of this thesis project.

There are some key advantages linked to applying a case study research strategy. Benbasat, Goldstein and Mead (1987) identified the following three distinct advantages:

- First, it allows studying of the phenomenon in its natural setting, and relevant theory to be generated through observing actual practice.
- Second, the approach allows the questions of *how* and *why* to be answered, as it provides a full understanding of the phenomenon's nature and complexity.
- Third, it is an appropriate way to approach early, exploratory investigations with a lot of unknown uncertainties regarding a phenomenon.

Relating this to the thesis project, the questions of how and why, holds a key towards identifying in what way and why certain factors influence the material flow, and how it can be made more efficient. The third advantage, that case studies are appropriate when approaching exploratory investigations, is helpful since there is a lot of unknown relations and factors affecting the studied phenomenon for this project. Also, being able to observe actual practice helps the mapping of the current state.

In addition to the advantages listed by Benbasat, Goldstein and Mead (1987), case studies are also a versatile research approach that can serve many purposes. Voss, Tsikriktsis and Frohlich (2002) bring up exploration, theory building, theory testing, and theory refinement/extension. Where exploration considers the early stages of a phenomenon when research areas are being uncovered and new theories are being developed. For theory building, the objective is to identify key variables of a phenomenon, relationships between the variables, and why the relationships exist. At the point of theory testing, developed theories are being tested to predict future outcomes. For the final refinement stage, existing theories are restructured in a better way, with the basis of observed study results (Voss, Tsikriktsis and Frohlich, 2002). Table 1 shows the match between the research purpose and research structure.

Table 1. Link between research purpose, question and typical research method, adaptation from Voss, Tsikriktsis and Frohlich (2002), and Stuart et al. (2002)

Purpose	Research question	Research structure
Exploration		
Uncover areas for research and theory development/ Explore territory	What is going on? Is there something interesting enough to justify research?	In-depth case studies Unfocused, longitudinal field study
Theory building		
Identify and describe critical variables/ Identify linkages between variables/ Causal understanding	What are the key variables? What are the patterns or linkages between variables? Why should these relationships exist?	Few focused case studies In-depth field studies Multi-site case studies Best-in-class case studies
Theory testing		
Test the developed theories, predict future outcomes	Are the theories robust? Is predictive capability validated? Are there unexpected behaviors?	Experiment Quasi-experiment Multiple case studies Large-scale sample of population
Theory refinement/extension		
Expand the map of the theory, improve the structure of the theories with respect to observed results	How generalizable is the theory? Where does the theory apply?	Experiment Quasi-experiment Case studies Large-scale sample of population

Utilizing case studies to build theory is a strategy of using empirical evidence from one or several cases to form theoretical constructs and propositions. Case studies generally contain bountiful empirical descriptions of a phenomenon from various data sources, making them useful for providing a data knowledge base from which to generate theory (Eisenhardt and Graebner, 2007). The research objectives in this thesis are most aligned with what Table 1 classifies as *theory building*, which indicates that the research questions or objectives should focus on key variables, linkages/patterns, and relationships. The findings of the thesis wish to strengthen existing theory within the field of warehousing and Lean, help fill in any knowledge gaps. Chosen research structure for this thesis is a single in-depth case study, which also is in alignment with the theory-building slot.

Another aspect to consider for the research strategy is the empirical research nature. Fisher (2007) created a taxonomy of different types of empirical research, in a 2x2 matrix. In which, the empirical research is grouped according to how structured and formal the interaction with the world is, and whether the outcome of the research is to prescribe or describe the phenomenon studied. The placement of this thesis in the taxonomy, shown in Figure 3, would be near the center but geared to the lower-right field, i.e., less structured, descriptive research. According to Fisher (2007), this placement is apt for a case study research approach.

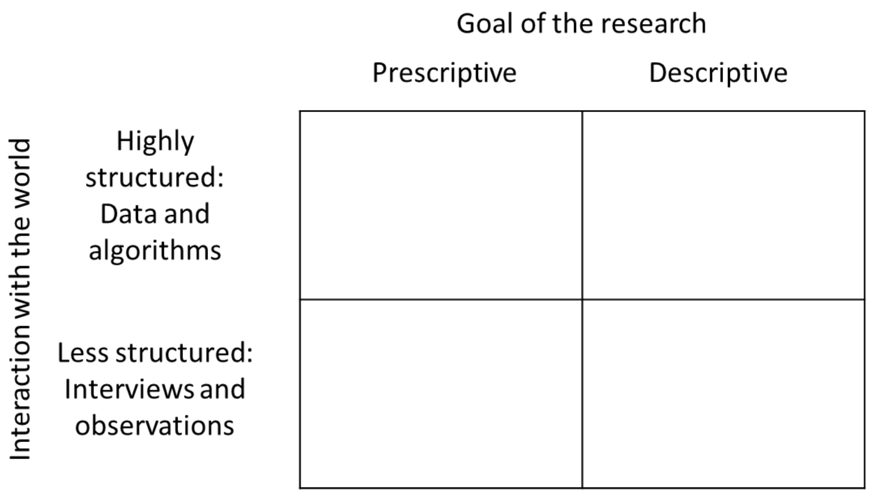


Figure 3. Taxonomy of empirical research (Fisher, 2007)

2.2 Research structure

The primary objective of the case study research methodology is to fully comprehend the phenomenon studied by using *perceptual triangulation*, i.e., compiling multiple sources to support the same evidence, to assure gathered facts are accurate (Meredith, 1998). While this indicates that there can be vast differences between specific methods and sources applied for any case study, they all tend to follow the same overall five-step research procedure. A derivation of which, from Voss, Tsikriktsis and Frohlich (2002), can be seen in Figure 4.

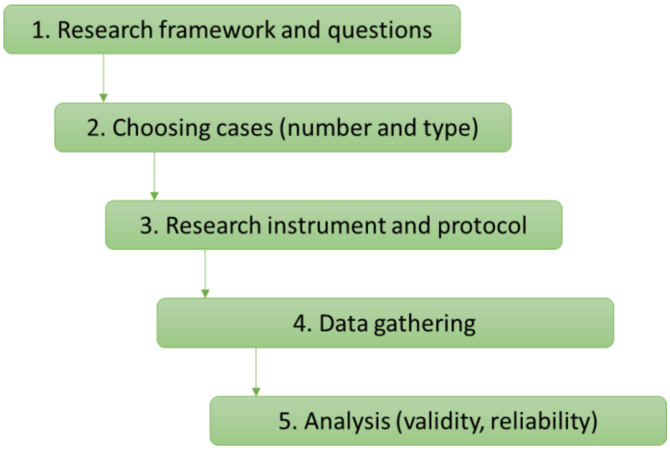


Figure 4. Case study research process, adaptation from Voss, Tsikriktsis and Frohlich (2002)

As Figure 4 suggests, the starting point for typical case research is to develop a research framework, constructs, and questions. Suggested as a first step in this initial stage, is to construct an underlying conceptual framework for the research. Followed by creating and defining research objectives and questions behind the study (Voss, Tsikriktsis and Frohlich, 2002; Stuart et al., 2002). The next step in the derived process from Voss, Tsikriktsis and Frohlich (2002), is to choose cases, both the amount and what type. Choosing to do a single case study has limits in generalizability but does provide greater depth. The types of case studies to choose from are either longitudinal or retrospective cases. The retrospective cases have the advantage of allowing collection of data on historical events, but it might be difficult to determine cause and effect, and participants may not fully recall significant events (Leonard-Barton, 1990; Voss, Tsikriktsis and Frohlich, 2002). There are advantages and disadvantages with each alternative, Table 2 shows a brief description of each option.

Table 2. Advantages and disadvantages with different case options, adaptation from Voss, Tsikriktsis and Frohlich (2002)

Options	Advantages	Disadvantages
Single cases	Greater depth	Conclusions have limited generalizability. Biases such as misjudging the representativeness of a single event or exaggerating easily available data
Multiple cases	Augment external validity, help guard against observer bias	Require more resources, less depth per case
Retrospective cases	Allows collection of data on historical events	Can be difficult to determine cause and effect, participants may not recall important events
Longitudinal cases	Overcomes issues with retrospective cases	Long time elapse and might thus be difficult to execute

Once the case design characteristics have been determined, the next step in the general case study research process is to develop research instruments and protocols to capture the data for upcoming analysis (Voss, Tsikriktsis and Frohlich, 2002; Stuart et al., 2002). Having a well-designed research protocol increases the validity and reliability of gathered case research data. The following step in the case study research process is to gather the data. As previously mentioned, triangulation is an underlying principle for case research, meaning applying a combination of data gathering methods. Among the several typical options to gather data lies interviews, questionnaires, direct observations, and archival research (Voss, Tsikriktsis and Frohlich, 2002; Benbasat, Goldstein and Mead, 1987). The final step of the research process is to analyze the gathered data. This step relies heavily on the integrative powers of the researcher. Contextual and data richness should be presented as much as feasibly possible, and a clear chain of evidence should be established (Benbasat, Goldstein and Mead, 1987). Data should be documented and coded, and tests for construct validity, internal validity, external validity, and reliability should be performed (Voss, Tsikriktsis and Frohlich, 2002).

In broad strokes, the thesis research structure follows this general case procedure. Where defining research objectives and questions, as well as defining and selecting a case is the first step. Followed by preparation for, and later execution of, the collection of data from multiple sources. Ending with data analysis, taking validity and reliability in regard, from which recommended course of action is provided and a conclusion of the study findings can be derived from. A graphical schematic of the research design, taking inspiration from Kembro and Norrman (2020), is presented in Figure 5, which shows in more detail how the research is conducted and its structure.

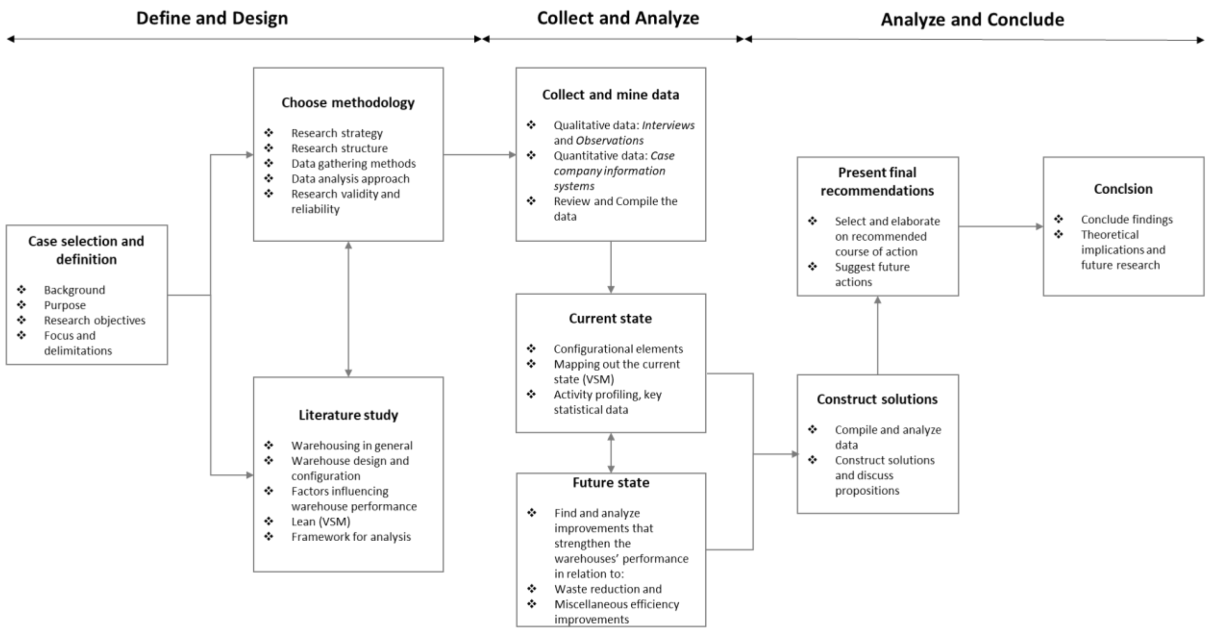


Figure 5. Schematic mapping of the study's structure, adaptation from Kembro and Norrman (2020)

Defining the unit of analysis and the level of aggregation of data (e.g., individuals, groups, divisions, companies, systems, or industries), at the outset of the study is imperative (Forza, 2002; Malhotra and Grover, 1998). Ensuring that the instruments used for gathering data collect the information at a consistent level are significant before making any analysis (Malhotra and Grover, 1998). The unit of analysis depicts the part that is researched in the study (Durach, Kembro and Wieland, 2017). For this study it is how to reduce wastes in the material flows at the case company warehouse, by applying the Lean principles as a mean to achieve a more continuous flow. The level of aggregation of data regards the sources and levels of data collection. Units of data collection are the horizontally gathered data i.e., a single entity or multiple entities, and the level of data collection is the hierarchical or vertical level from which data is gathered and could be all from individuals to firms (Durach, Kembro and Wieland, 2017). This study has the level of data collection set on a plant level (the warehouse) and considers just the one entity, no outside entities are investigated for the study.

2.3 Literature review

When performing any empirical research, it is imperative to obtain a strong grounding in relevant literature, identifying research gaps, and forming research objectives or questions addressing the gaps (Eisenhardt and Graebner, 2007). A literature review is therefore performed before collecting any data for this thesis study. This literature review attempts to follow the overall fundamentals of the six-step procedure for systematic literature reviews presented by Durach, Kembro, and Wieland (2017). Starting by defining the research objectives and determining inclusion/exclusion criteria. This is then followed by retrieving a sample of potentially relevant literature sources, to which the inclusion/exclusion criterion is applied to weed out irrelevant ones. The remaining sources are reviewed and compiled to be presented in the literature findings.

The purpose of the conducted literature review is to obtain a comprehensive understanding of the investigated topics and provide sufficient background coverage and the tools necessary to form the framework for analysis. This entails scouring the internet for relevant information on the subject, using reputable databases, where academic journals are the primary target. More specifically, with the purpose of the research circumventing the topic of warehousing and identifying efficiency issues and remedy suggestions, two branches of searches are conducted, one focusing on warehousing and correlating keywords and the other focusing on Lean. Since the purpose and objectives relate to efficiency, and that Lean is a known practice for obtaining a more efficiently oriented mindset, and the fact that the case company warehouse is already using it, it became a natural choice to gear the literature review in that direction.

With the first step in place, the next is to determine the inclusion/exclusion criteria and collect a sample pool using a combination of apt keywords. Starting with the criteria, since the topics of warehousing and Lean are older and established concepts, and that a comprehensive understanding is desired, the dates for the first out of two searches are set to 2005 and newer to ensure the inclusion of the fundamentals. There are some sources used that are older than that as well, these are derived from applying a citation pearl growing strategy, in which key sources found in the articles' reference lists are reviewed and applied as fit (Ramer, 2005). The reasoning for this is that when aspirating the fundamentals, it seems apt to go straight to the source. Examples of such sources found are Rouwenhorst et al. (2000), van den Berg and Zijm (1999), Hayes and Wheelwright (1979), and Hines and Rich (1997), these were all prominent in some of the articles. As a baseline understanding is developed, more branches of the topics are uncovered, making for an additional literature search to be made. For this search, more recently published articles are targeted, dating back no more than five years, to grasp the current understanding. Older articles are wanted for topics where the fundamentals have not been completely revitalized, unlike for instance automation for which a more recent view is needed. Besides the dates, another inclusion/exclusion part is that the academic journals should be well-reputable.

The keywords used, either as standalone or combined, are *warehousing, warehousing operations, warehouse design and configuration, warehouse management, warehouse trends and challenges, perishables warehouse, cold chain logistics, material flow, workforce scheduling (workload), automation, operational performance, operations management, Lean warehousing, Lean principles, critical success factors, wastes, Lean production, Lean manufacturing, Lean Six Sigma, value stream mapping.* Using these different keyword combinations and excluding irrelevant articles based on the criteria, a sample of articles could be gathered to be read-through and reviewed. Relevant ones are composed with its significant parts being presented in the thesis report. It is important to put the single author bias into question regarding this literature review though. An attempt to enhance the study finding's reliability is made by trying to follow the outline for systematic literature reviews as presented by Durach, Kembro and Wieland (2017), by setting up criteria and stating used keywords to present a sample of articles.

There are some additional sources used besides academic journals to complement the literature review. One of the most featured sources is the Bartholdi and Hackman (2019) *Warehouse and Distribution Science* book. This source provides significant inputs about the fundamentals of warehousing and is used as a staple and deemed reliable as it is used as course literature at Lund University. In addition, in the frame of reference section Mattsson and Jonsson (2013), Mattsson (2012), and Lumsden (2007) are also used. These are Swedish sources, used merely to complement descriptions about fundamental aspects regarding material flow. Another source used that is not an academic journal is ASQ (2021a-f). It is the website for the American Society for Quality and is used in the thesis to describe the practicalities of the Lean tools and approaches, chosen since it presents the basics with an intent to educate.

2.4 Data gathering

Collecting data can be accomplished in many ways and can come from a variety of sources. The specifics of any one data gathering design are rarely the same, as it is a situational proceeding (Forza, 2002). For case research, as previously mentioned, typically a combination of different methods is applied to collect the data when studying a phenomenon, i.e., triangulation, which is an underlying principle for the research approach (Voss, Tsikriktsis and Frohlich, 2002; Meredith, 1998). Among the many means that can be utilized, some common ones are interviews, direct observations, questionnaires, internal company documents, archival records, and artifacts (Voss, Tsikriktsis and Frohlich, 2002; Stuart et al., 2002). Each of which can be used and are suitable in different contexts and provides different types of data. It is common to distinguish data as either qualitative or quantitative. Qualitative data considers soft metrics and usually comes in word format. It is commonly utilized to make descriptive explanations of a phenomenon. While quantitative data refers to the opposite, hard values, and metrics in numerical format. The quantitative data is often used to provide answers to strictly quantitatively loaded questions, such as averages, and can often serve as a baseline for performing various calculations and statistical analyses about a phenomenon (Patel and Davidson, 2011).

For this study, a combination of semi-structured interviews, direct observations, and case company data derived from the *enterprise resource planning (ERP)* system/WMS is collected. This provides sufficient data to properly fulfill the purpose and research objectives of the study. Apt literature is gathered, mainly in the forms of various journals and a handful of books, to provide necessary background and frameworks, fill in potential knowledge gaps, and get an understanding of the current literature about the topics. Both quantitative and qualitative data are gathered through the data collection means. A summarizing table of what type of data is being collected and why it is collected can be seen in Table 3. Using this sort of multi-faceted approach for collecting the data for the study is consistent with typical case research data gathering approaches and the concepts of triangulation (Stuart et al., 2002).

Table 3. Data gathering approaches and purpose

Collection method	Data type	Purpose	Comment
Interviews	Qualitative	Configurational understanding/ Miscellaneous	Gain deeper, more nuanced understanding of the configuration and fill in data gaps
Direct observations	Qualitative	Mapping processes/ Value stream mapping	Get immediate impressions and gain understanding of layout and processes
Case company systems data	Quantitative	Activity profiling/ Contextual factors	Get numerical data about the warehouse for activity profile and contextual factors

2.4.1 Qualitative data

For case research, much of the field data is typically gathered from interviews with various respondents. Interviews can be conducted in many ways, serving different agendas and have different designs (Voss, Tsikriktsis and Frohlich, 2002). The two main aspects to consider when gathering information through interviews, according to Patel and Davidson (2011), is the degree of standardization of the questions, the design and order, and the structural degree i.e., the extent to which the interviewee has free range to answer, making own interpretations and connecting to personal experiences in relation to the questions. Interviews with low standardization mean that questions are made up as the interview goes along and that questions are presented in a suitable order for the interviewee. Whilst with high standardization the interview has predetermined questions and order. Low structure in the interview, means the interviewee is allowed maximum range for their answers, while high means the different answer alternatives that can be given are limited and predetermined. Besides these two aspects, it is also important when conducting interviews to keep in mind the sequencing and the formulation of the questions, what type of purpose the interview serves, and ensure that the interviewer is impartial and understands the content (Patel and Davidson, 2011; Voss, Tsikriktsis and Frohlich, 2002).

For this study, all interviews are semi-structured, though some are more standardized and structured than others depending on what purpose the specific interview serves. The reason why there are different degrees of standardization and structure is that the interviews serve as both a primary tool and complementary tool for the data collection. It serves as a primary tool for the gathering of data about the warehouse's configurational elements, and as a complementary tool for e.g., constructing the current state analysis. It is also used to fill in data gaps left from the case company data, observations, and literature. Interviews thereby make up a big portion of the gathered data, particularly the soft qualitative metrics.

Distinguishing interviews from observations, there are five interviews conducted in this study. Four of these are conducted on-site and one over a communication platform (Microsoft Teams) for practicality matters. Four of the interviews are recorded, with permission from the interviewee(s), and later transcribed for increased accuracy (Voss, Tsikriktsis and Frohlich, 2002). Conducted interviews with featured purpose and interviewees can be found in Table 4. One of the interviews is also included amongst the observations, interview number one, this is because it is conducted more informally in combination with a guided tour of the warehouse. Interview guides can be found under Appendix A.

Table 4. Conducted interviews

No.	Date	Interviewee(s)	Purpose of interview	Traits
1	2021-02-26	Warehouse Manager, Sami Kuutti	Get to know the warehouse basics, introduction (guided tour)	On-site Notes
2	2021-03-19	Senior Warehouse Manager, Jonas Granerås Warehouse manager, Sami Kuutti	Gain an understanding of the warehouse configuration and its configurational goals	On-site Recorded
3	2021-03-24	Warehouse Manager, Sami Kuutti Team Leader, Rickard Widegren	Gain an understanding of the three main material flow channels	On-site Recorded
4	2021-03-25	Senior Warehouse Manager, Jonas Granerås Warehouse manager, Sami Kuutti Team Leader, Rickard Widegren	Supplementary interview to interview no. 2	On-site Recorded
5	2021-05-11	Warehouse Manager, Sami Kuutti	Supplementary interview to interview no. 2 and no. 3	Microsoft Teams Notes

The purpose of the interviews is mainly to obtain a holistic understanding of the warehouse and its material flows. Therefore, targeted interviewees are people with an overview of the warehouse and a comprehensive understanding of its configurational elements. Positions with a holistic understanding geared towards the warehouse and its activities are sought after, presumably this entails the warehouse management. After discussion with the case company supervisor (the Senior Warehouse Manager), this comprised of three interviewees, the Senior Warehouse Manager, the Warehouse Manager, and one of the Team Leaders. Team Leader refers to someone whose main responsibility is managing the different shift groups, accompanied by some other specialty field, in this case projects. To provide more nuanced answers, two or three of them were interviewed simultaneously for three of the interviews, as Table 4 indicates. Why there were only two attendees for interview numbers two and three, had to do with time availability. Each interview was arranged in advance and in contact with the case company supervisor, to find suitable time windows.

Besides these five interviews and the observations discussed in the previous subsection, there also occurred informal shorter discussions over phone or email, mainly to clarify certain aspects about the warehouse or previous interviews. Shorter informal discussions also occurred in relation to the observations. Worth noting is that the semi-structured interview format is ill-fit considering the author’s lacking interviewing experience. Having a structured format would be more apt, especially considering it is a single author. However, since there is a lot to uncover, and that the author is unfamiliar with many aspects of the warehouse, more open-ended exploratory questions are required. The single author bias is attempted to be overcome by preparing interview guides in advance and performing multiple interviews on the same subject line if necessary to supplement anything lost by the solo interviewer perspective.

According to Patel and Davidson (2011), observations in the research context must, to be a valid gathering tool, be planned on beforehand, and the information gathered must be registered systematically. The advantage of the approach is that it can collect information about a phenomenon’s behavior in its natural setting as it occurs. There exist a few different types of observations, there are structured and unstructured, as well as direct and participant observations. Structured observations entail studying the frequency of occurrence for known behaviors of a phenomenon. The unstructured ones are in contrast used for exploratory purposes, in contexts where the aim is to gather as much information as possible. All noted behaviors are then registered and compiled for analysis (Patel and Davidson, 2011). For the second distinction, direct observation entails that the researcher remains outside of the analyzed system and is passive, only noting events. For the participant-observations, the researcher takes on an active role in the system, for instance, acts as a picker in a warehouse (Voss, Tsikriktsis and Frohlich, 2002).

The gathered data through observations in this thesis study is done predominantly in the form of unstructured direct observations. Observations play their biggest part in this study during the construction of the current state mapping, making it fitting to have direct unstructured observations since the aim is to gather as much information as possible while observing the warehouse’s natural setting. Besides this main role, observations are also used to support the data gathering in subsequent parts of the study, for which they are conducted similarly. There are a total of six observations for this study, all of which are featured in Table 5 accompanied by their date and purpose. They are performed to either complement the interviews, or to provide impressions of what is studied in its natural setting. Observations number one and two are performed in conjunction with the interviews to provide real imagery of what has just been discussed, the others are performed to accomplish a specific purpose, each stated in Table 5. The first two observations are performed accompanied by the Warehouse Manager, Sami Kuutti, and subsequent one by one of the Team Leaders, George Inal. These three first observations had more of a guided tour structure with notes taken throughout and informal discussions. The first one informally follows the interview guide in Appendix A and was substantial enough to also categorize as an interview in Table 4. The last three observations are accomplished solo, by walking around the warehouse facility taking notes about the investigated areas to satisfy the purpose of the observation as described in Table 5.

Table 5. Performed observations

No.	Date	Purpose of observation	Additional attendee(s)
1	2021-02-26	Get a grip of the warehouse basics; Introduction (guided tour)	Warehouse Manager, Sami Kuutti
2	2021-03-19	Gain imagery of the warehouse proximity	Warehouse Manager, Sami Kuutti
3	2021-03-23	Gain an understanding of the working procedures	Team Leader, George Inal
4	2021-03-24	Get a grip of the three material flow channels	None
5	2021-03-26	Supplementary observation of the three material flow channels (focus on the carousel and inbound/outbound)	None
6	2021-04-13	Investigate storage capacity and picking locations	None

The observations either takes place during a Tuesday, Wednesday, or Friday, which is based on the supervisor's time availability. This limits the perspectives and conclusions made from the observations. Each observation either takes place during the morning or afternoon shift at the warehouse. Observations number two and six takes place during the afternoon shift, the others during the morning. No observations are made during the night shift or weekend shifts, which again limits any conclusions to be made solely from the observations. To help support any findings through the observations, questions are asked during the interviews regarding any differences between the shifts and days, and data is gathered to analyze any activity differences between the shifts and weekdays. The single author aspect should be noted here as well since nuance is lacking from any perceptions made.

2.4.2 Quantitative data

The case company data refers to raw data extracted from the investigated warehouse's information systems, mainly from its ERP or WMS, but also supplementary information from smaller independent systems e.g., the Commissioner. This type of data is provided upon sent request to the case company supervisor, or someone in the IT department with access to the information systems, who then comprises and returns the deemed most relevant available data. The data is extracted to fit an Excel format for the numerical data e.g., picking data, or pdf for images e.g., blueprints for the layout.

Requested numerical data for this thesis include customer order characteristics, product and SKU characteristics, utilization figures, shipments received and shipped, demand characteristics, *key performance indicator (KPI)* measures, etc. together with complementary figures such as various maps and charts, and available organizational records. Luckily, right before the data gathering for this thesis study, the case company warehouse had conducted and finalized a project about cost transparency, which entailed that much of the requested data for this study had already been compiled. This helped save a lot of time, that otherwise would have been required to mine raw data from the information systems. However, some of the data had to be redacted due to confidentiality, this mainly regarded cost figures.

The case company data is mainly collected to create an activity profile and obtaining an understanding of the warehouse activity, but it is also collected to serve as complementary data for the current state mapping in the form of e.g., layout blueprints. The overall aim is to gather sufficient data to provide coverage for making improvement suggestions to the warehouse’s material flow channels.

2.5 Data analysis

When data has been gathered it needs to be processed, systematized, and compressed to provide answers to the research questions or objectives (Patel and Davidson, 2011). Data analysis is a vital step for any research since the raw data in itself does not provide any clear answers. Voss, Tsikriktsis and Frohlich (2002), talk about documenting and coding the gathered data as a first step when conducting the analysis. Where documenting constitutes typing up notes and/or transcripts, to produce a narrative, and coding of categorizing made observations and collected field data, to compare incidents in the same categories to develop theoretical properties of the categories and their dimensions (Voss, Tsikriktsis and Frohlich, 2002).

There are several approaches to choose between to analyze the data depending on the context. Methods to choose from for processing the data range from qualitative processing i.e., interpreting textual data, to quantitative processing using statistical methods to analyze the numerical data (Patel and Davidson, 2011). Qualitative processing requires the data to be well coded to extract relevant information since the qualitative data typically comes in a narrative form (Saunders, Lewis and Thornhill, 2007). The end product of the qualitative processing is often a text consisting of quotations from interviews or observation notes combined with own made comments and interpretations (Patel and Davidson, 2011). For quantitative processing, Patel and Davidson (2011) mention that it is important to document the procedure to increase the trustworthiness of the outcome. For analysis, a combination of different statistical tools, graphs, and charts can be used to make sense of its behavior, relationships, trends, and to draw conclusions (Saunders, Lewis and Thornhill, 2007).

The data analysis for this study uses a framework for analysis (presented in the final heading of the frame of reference section) as guidelines for compiling and structuring the gathered data. Thus, data is presented systematically, and the case’s unique patterns and behaviors become intimately familiar by applying within-case analysis before making any generalizations. Since the two research objectives are to identify problem areas and provide remedy suggestions, a root cause analysis is conducted on each of the identified problems. The Lean technique 5 whys are used, and it is conducted to provide an understanding of where the identified problems stem. Using this provided baseline, remedy suggestions for the identified problems are successively constructed. Problems are identified using Lean approaches, mainly value stream mapping and Spaghetti diagrams, to visualize any redundancies in the material flows. With empirical and literature findings as a baseline, remedy suggestions are drafted and checked for viability against the Hayes and Wheelwright (1979) product-process matrix and the Chopra and Meindl (2007) cost-responsiveness efficient frontier regarding the case company warehouse’s relative positioning in the models. The literature section provides an explanation of what these models are. The gathering and analysis of data overlap in the study structure. This is partly because of the succession of the data collection where some data must be built upon previously gathered, but also to provide the study with more flexibility. More flexibility in the sense that data could be gathered retroactively to help provide a more comprehensive analysis. Following the framework for analysis, data is gathered to provide the necessary case-specific complements to the literature findings and to provide answers to the research objectives.

To fully collect the data needed for the research objectives, both quantitative and qualitative data are gathered. The quantitative data provides a baseline of *what* transpires in the warehouse, which the qualitative data complements by providing explanations that fill in any gaps in the data by adding soft metrics that cannot be gathered numerically e.g., *how* and *why* something works and looks the way it does. Quantitative data is predominantly gathered to perform an activity profile and to identify the contextual factors influencing the warehouse performance. Data is gathered with findings from literature kept in mind, to construct a sufficient activity profile from which recommendations and conclusions could later be based on. This data consists mainly of numerical raw data that stems from the information systems used at the case company. The performed analysis here is finding and interpreting patterns, relationships, and relevance amongst the raw case company information systems data. Also, to link and compare it to the theoretical findings from the frame of reference. Qualitative data is collected to map out the configurational elements of the warehouse and construct the value stream map that is used for identifying the problem areas. The relative influence of the problem areas, which indicated where to direct focus, is based upon the empirical findings in the study and the case company informants' perspectives. The qualitative data type is either transcribed from recorded interviews or comes in the form of documentation or notes during, or shortly after a conducted interview or made observation. This textual qualitative data is also a prominent feature for the second research objective and step of the framework for analysis to discuss and review alternative solutions to the identified problem. Thus, data for both current and future state is collected and organized in said manner. The outcome of which is identified alterations to be made to improve the material flow efficiency.

2.6 Validity and Reliability

The goodness of the measures in any research is usually based on their validity and reliability. Where the validity concerns if the right concept is measured, as a lack thereof introduces systematic errors to the measures. Reliability regards the consistency and stability in the measures and introduces random errors if lacking (Forza, 2002). For any case research, it is important to pay attention to these concepts. Validity and reliability consist of four main dimensions. *Construct validity* is one of these, which is the extent to which operational measures for the studied concepts are established. Another is *internal validity*, the extent to which causal relationships can be established, and *external validity*, which is the knowledge of whether the study's findings can be generalized beyond the specific case context. The last one is *reliability*, which refers to the extent to which the same study will be repeated with the same results (Voss, Tsikriktsis and Frohlich, 2002). Table 6 presents these four dimensions and provides tactics on how to help ensure them.

Table 6. Reliability and validity in case study research, adaptation from Voss, Tsikriktsis and Frohlich (2002)

Test	Case study tactic	Phase of the research
Construct validity	Using multiple sources Establish chain of evidence Key informants review case study report draft	Data collection Composition
Internal validity	Pattern matching Explanation building Time-series analysis	Data analysis
External validity	Replication logic in multiple case studies	Research definition and design
Reliability	Case study protocol Develop a case study database	Data collection

This study attempts to comply with some of the case study tactics presented by Voss, Tsikriktsis and Frohlich (2002). For the construct validity it does so through using multiple sources of evidence to see that measured constructs do not differentiate between sources, and by having key informants, in this case the supervisors, review drafts of the report. To ensure the internal validity and the extent of causal relationships i.e., that no outside variable is affecting or causing the investigated phenomenon, the gathered information is triangulated in search for patterns and similarities between the sources e.g., when aiming to obtain a comprehensive understanding of the order activity in the warehouse both the quantitative WMS data and qualitative interview data is reviewed in search for similarities. External validity, concerning the generalizability of the study findings, is something that is seen as a general weakness for single case studies (Voss, Tsikriktsis and Frohlich, 2002). This study's findings are in turn lacking in this regard, as research performed at one company is usually not sufficient for making any general conclusions about the findings. Subjecting the research to one company's setting may not lend itself applicable in a different setting. The last item out of the four dimensions is reliability, which is adhered to through keeping a research protocol over the research process, documenting it in detail. This ensures that if repeated the study would achieve the same results.

Each of the four dimensions presented by Voss, Tsikriktsis and Frohlich (2002) is considered throughout the research process. They are each regarded at their relevant stages, where the construct validity and reliability are considered in the data collection phase of the research process, in the forms of a triangulation approach and documentation of the process. While the internal validity is considered in the data analysis stage, by reviewing the different data gathering sources in the search for similarities. External validity is considered at the initial stage of the study, regarding the formulation of the research objectives. While case-specific, the ROs are formulated more objectively and generally to increase the transferability of the findings to other contexts. The extent to which external validity is achieved is later discussed, keeping in mind that the generalizability of the findings cannot be fully ensured due to the constraints of a single in-depth case study. The goodness of the measures is regarded with these dimensions in mind, to achieve satisfactory research quality to support the findings of the study. Single author bias has relevance in this thesis study, it is attempted to be overcome by having key informants review the logics in the findings, to gain an additional set of eyes on it and hopefully avoid tunnel visioning. Objectivity is strived for and attempted through the data gathering process structure.

3 Frame of reference

This section presents relevant literature to support the study. It is divided into five areas, where the first four provide the literature basis for upcoming sections, and the last one presents the framework for analysis. It starts with three blocks regarding warehousing, starting broad with Warehousing in general, to Warehouse design and configuration, and lastly to Factors influencing performance. The last part presents literature about key areas of the Lean philosophy. The framework for analysis presents the linkage between the frame of reference and the empirical findings and its connection to the research questions. Figure 6 visualize the blocks that make up the structure of the section.

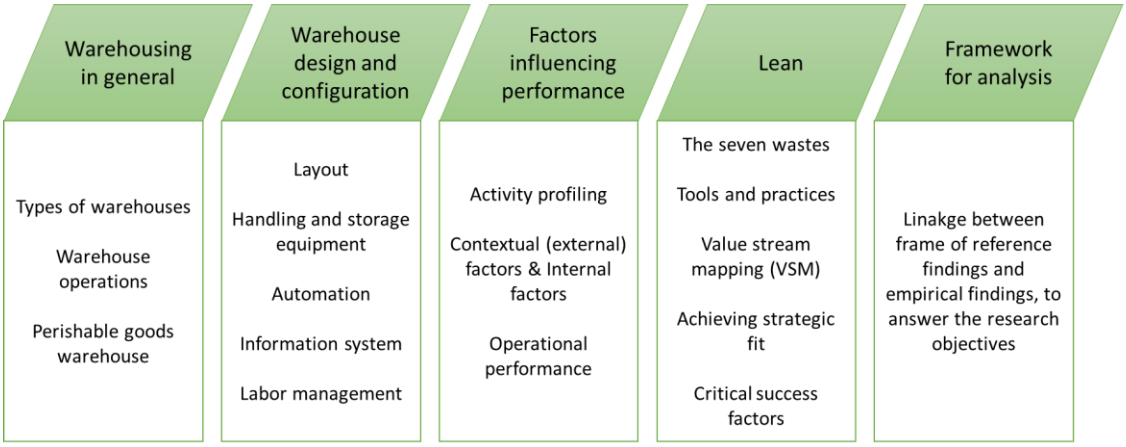


Figure 6. Frame of reference structure

3.1 Warehousing in general

Bartholdi and Hackman (2019) describe a warehouse as “the points in the supply chain were products pauses, however briefly, and is touched”. They serve an intermittent role in a supply chain, for cases where direct distribution to customers would not be appropriate or when holding inventory would serve a strategic advantage (Kembro, Danielsson and Smajli, 2017; Baker and Canessa, 2009; Kembro, Norrman and Eriksson, 2018). While warehouses come with significant expenses in labor and capital, they are often a necessity for businesses (Bartholdi and Hackman, 2019). Mainly because of their ability to help match supply with demand and consolidation of products, but they also help with managing the distribution process and reduce transportation cost and enables postponement of product differentiation by configuring generic products close to the customer (Kembro, Danielsson and Smajli, 2017).

A warehouse’s main objective is to manage, as efficiently as possible, the flow and storing of goods, while simultaneously provide flexibility for resource management (Martins et al., 2020). The typical warehouse has goods moving through the following sequence of activities: receiving, put-away, picking, packing, and shipping (Bartholdi and Hackman, 2019; Martins et al., 2020; Gu, Goetschalckx and McGinnis, 2007; Rouwenhorst et al., 2000; Gunasekaran, Marri and Menci, 1999). Depending on the customer the warehouse serves, it can be distinguished into three types: *distribution warehouse*, *production warehouse*, or *contract warehouse* (Kembro, Danielsson and Smajli, 2017; van den Berg and Zijm, 1999). Where a distribution warehouse consolidates products from different suppliers (sometimes assembles too) and distributes these to customers. Production warehouse stores materials in a production process i.e., storing raw material, work-in-progress, and finished products in a production facility. The last type, the contract warehouse, is a type of warehouse where an external part is liable for and performs the warehouse operations on a customer’s behalf (van den Berg and Zijm, 1999). Though the exact nature often differs, there is a similar systematic way of thinking about managing a warehouse system, regardless of industry or purpose (Bartholdi and Hackman, 2019).

3.1.1 Material flow

In a logistics context, material flow regards the movement of raw materials, work in process, and finished products (Mattsson and Jonsson, 2013). It is, in view of a supply chain, the object(s) of which is passing through a sequence of processes from its place of origin to the final user or customer (Bartholdi and Hackman, 2019). To achieve the typical primary goals of any supply chain of delivering products at a low cost and when they are needed, it is important to manage the material flow efficiently (Lumsden, 2007). An ideal material flow would be a seamless continuous movement from start to finish. For many reasons this is never a reality though, flows are typically intermittent with varying speed between actors and nodes (Mattsson and Jonsson, 2013; Bellgran and Säfsten, 2010). The whole supply chain's effectiveness is increased by simplifying and improving the efficiency of the material flow (Childerhouse and Towill, 2003). Doing it correctly is all about ensuring that the right material is received by the right recipient at the right time (Bellgran and Säfsten, 2010). In today's modernized supply chains, any flow disruptions pose cascading effects downstream (Bartholdi and Hackman, 2019). A warehouse's core activities from inbound to outbound, are determined by and revolves around the flow of materials (Lim, Bahr and Leung, 2013). Warehouses have over the last decades been refined and adopted designs that ensure smooth flows and efficient movement downstream. The outcome of which is supply chains that deliver greater value (Bartholdi and Hackman, 2019).

3.1.2 Main warehouse operations

Though warehouses can appear very different they all tend to follow the same material flow pattern (Bartholdi and Hackman, 2019). To fulfill their purpose, typical requirements of a warehouse is that they can receive SKUs from suppliers, put-away and store SKUs, process customer orders, pick the orders, assemble them for dispatch, and load the complete orders for transport and shipment to the customer (Gu, Goetschalckx and McGinnis, 2007). The main, basic warehouse activities can be compiled into receiving, put-away, picking, and dispatch (packing and shipping), which in turn can be divided into two categories: inbound and outbound operations (Martins et al., 2020; Bartholdi and Hackman, 2019; Gunasekaran, Marri and Menci, 1999). Figure 7 shows the main warehouse activities and under which category they fall.

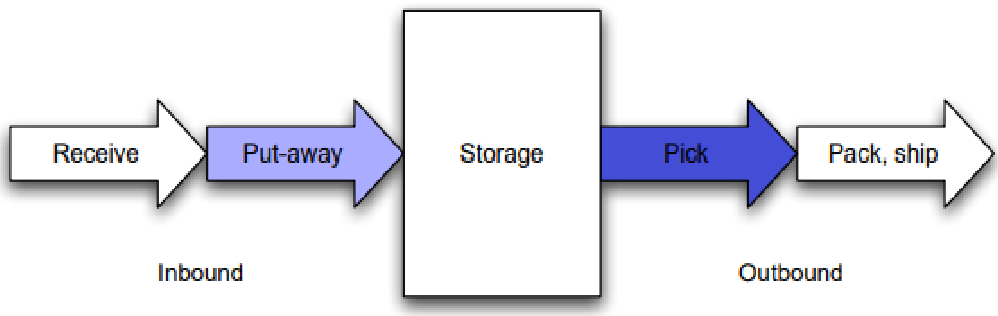


Figure 7. Basic warehouse activities (Bartholdi and Hackman, 2019)

The inbound activities consist of receiving and put-away of the SKUs into storage (Bartholdi and Hackman, 2019). The receiving activities represent the first process step in the warehouse (Rouwenhorst et al., 2000). To which, the products either arrive by internal transport or truck and typically in larger units e.g., pallets (Rouwenhorst et al., 2000; Bartholdi and Hackman, 2019). After arrival, products are unloaded from the transport carrier and often inspected to ensure the quality of the goods meets agreed-upon conditions (de Koster, Le-Duc and Roodbergen, 2007; Martins et al., 2020; Bartholdi and Hackman, 2019; Rouwenhorst et al., 2000). Afterward, the goods are often scanned to register their arrival and that ownership of the goods has been accepted (Bartholdi and Hackman, 2019). Following the unloading, the products may be transformed (repackaged) into new SKUs, in preparation for storage (Rouwenhorst et al., 2000). Bartholdi and Hackman (2019) estimate that in a typical warehouse the receiving operations account for about 10 percent of the total operational cost.

After receiving the goods, the put-away operation of placing the SKUs into storage locations follows (de Koster, Le-Duc and Roodbergen, 2007; Martins et al., 2020; Rouwenhorst et al., 2000). Bartholdi and Hackman (2019) emphasize that apt locations must be determined before being placed into storage. This step is significant since the storage location largely influences how fast and at what cost the SKUs can subsequently be picked for customer orders. Bartholdi and Hackman (2019) mention some algorithms that can help determine where to put-away an SKU, *next fit* and *first fit*. Where next fit directs attention to one shelf at a time and if the SKU in question fits it is placed there, otherwise the shelf is deemed full and not reconsidered. First fit is similar to next fit, but the difference being that it tries the SKU on each partially loaded shelf and places it on the first one that fits, if none fits it opens up a new empty shelf and places it there, and then the process continues.

As an SKU is placed in storage it should be scanned to register its placement to the information system, to help it plan the retrieval process more easily (Bartholdi and Hackman, 2019). The storage area can have very different appearances depending on the industry, one example of a typical configuration consists of two parts, a reserve or bulk storage area and a forward area for easy retrieval. Forward areas often have smaller SKUs, with items from the reserve being transferred in when needed, a so-called *replenishment* (Rouwenhorst et al., 2000). The put-away operations typically require quite a bit of labor, considering the distance needed to travel to the storage locations. Normally it accounts for about 15 percent of the total operating expenses in a warehouse (Bartholdi and Hackman, 2019).

The outbound operations include picking customer orders, packing and loading the picked goods, and shipment to customer. Order-picking is first in line in the outbound processes, and it refers to the retrieval of items from storage. This can be accomplished manually or automatically to some extent (Bartholdi and Hackman, 2019; Rouwenhorst et al., 2000). What items are being retrieved is based on the customer orders, which are made up of order lines, where each line represents an SKU and the demanded quantity (de Koster, Le-Duc and Roodbergen, 2006). Typically used is a WMS, which is a software system that orchestrates warehousing activities, that checks for storage availability and any shortages. Depending on what functions are active, the WMS may organize picking-lists to match the layout and the warehouses' activities. There are two types of order picking procedures, the more labor-intensive less-than-carton quantities or broken-case picking, and carton picking, which often can be automated (Bartholdi and Hackman, 2019). It is not uncommon that multiple order-picking systems are applied in one warehouse (de Koster, Le-Duc and Roodbergen, 2006). For warehouses, a key statistic is to measure the flow time, which refers to the elapsed time from received order to loading and shipping of the demanded goods. Order-picking is a time-consuming activity and typically accounts for more than half of warehouses' operating expenses, where traveling constitutes the greatest part (Bartholdi and Hackman, 2019). To operate a warehouse efficiently it is therefore essential that the order-picking process is robustly designed and optimally controlled (de Koster, Le-Duc and Roodbergen, 2006).

Once picked the goods are moved to the dispatch area, where they are normally checked and packed before being shipped away (Rouwenhorst et al., 2000). Packing can be a labor-intensive process. Each part of the customer order must be handled, which is why it is common to meanwhile check the goods at this stage to ensure the customer orders are complete and up to agreed standard. Packed orders are often scanned to register their availability for shipping (Bartholdi and Hackman, 2019). The last stage of the outbound processes is the shipment, where the picked goods are loaded onto trucks, trains, or some other carrier (Rouwenhorst et al., 2000; Martins et al., 2020). With shipping, there are usually larger units being handled than in the picking, due to the consolidation, which consequently means there is less labor at this stage. Once loaded it is typically scanned to register its ready departure (Bartholdi and Hackman, 2019). Order-picking is by far the most expensive and time-consuming process out of the basic warehousing activities, for which transportation is typically the most prominent culprit (Bartholdi and Hackman, 2019).

3.1.3 Other operations

While most warehouses contain the same basic operations described above, many warehouses also perform some special operations suited for their situation. Some more common additional activities performed in warehouses are cross-docking, returns, and miscellaneous value-adding activities (Faber, de Koster and Smidts, 2013). The first type of special operations, cross-docking, is essentially a high-speed warehouse. Where goods are moved directly from receiving to shipping, avoiding the intermediate steps of put-away into storage and subsequent handling steps (Baker and Canessa, 2007). Cross-docks are typically long and narrow with doors around the perimeter, an example can be seen in Figure 8. The main benefits of this special type of warehouse configuration are the fast movement of goods and the cost savings from reduced storage and materials handling (Bartholdi and Hackman, 2019).

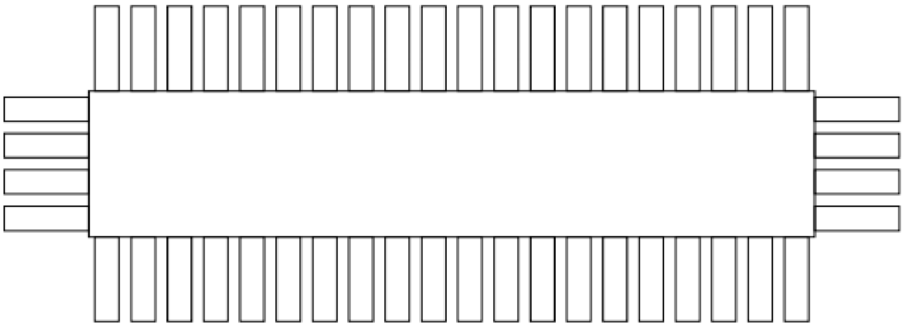


Figure 8. View from above of a typical high-volume cross-dock (Bartholdi and Hackman, 2019)

Value-adding activities are a trend that is becoming more common for warehouses. Where, beyond the traditional consolidating and shipping of customer orders, additional value-adding processing is included. Amongst the many types of value-adding processes lies ticketing or labeling, repackaging, kitting, postponement of final assembly, and invoicing (Bartholdi and Hackman, 2019; Baker and Canessa, 2007). The reason for performing these value-adding activities could e.g., stem from the manufacturing department wanting to postpone the product differentiation, or the customers needing to outsource the activities as they might be too expensive or cumbersome to execute by own hand (Bartholdi and Hackman, 2019).

Many warehouses today must handle returns, which refers to backward distribution or *reverse logistics* and considers the physical flow of items from consumers to retailers and return or distribution centers (Bartholdi and Hackman, 2019; Hübner, Holzapfel and Kuhn, 2016). Returns are an expensive ordeal and can cost up to ten times the normal cost of shipping a product (Bartholdi and Hackman, 2019). However, convenience and service quality are becoming increasingly significant to satisfy today’s consumers. Thus, having a return option has in many industries, especially for e-commerce, become a necessity (Hübner, Holzapfel and Kuhn, 2016). Currently though, it is for many warehouses deemed as one of the most challenging and time-consuming operations to manage satisfactorily (Kembro, Danielsson and Smajli, 2017).

3.1.4 Perishable goods warehouse

Amongst the different types of warehouses lies the perishable goods warehouse, which comes with its unique set of requirements and challenges (Bartholdi and Hackman, 2019). Perishables here refer to products with a short shelf life that generally requires refrigeration. It is commonly applied and featured in industries such as food, pharmaceuticals, and chemicals (Bartholdi and Hackman, 2019; Chaudhuri et al., 2018). Managing a supply chain with these types of products, a so-called *cold chain*, have specifically high demands on quality, timeliness, and safety, throughout all stages of the supply chain (Göransson, Nilsson and Jevinger, 2018). Maintaining integrity in production, processing, distribution, and transportation is vital, as deterioration of the goods can cause adverse effect on human health and substantial economic losses (Chaudhuri et al., 2018).

Perishable goods warehouses have additional strain on operational efficiency compared to the typical warehouse. Since perishable products typically must be rushed to the customers, maintaining only short periods in the warehouse, often merely hours (Bartholdi and Hackman, 2019). Therefore, it is crucial to optimize the time required to issue a customer order or to receive and put-away units in the warehouse (Rizzi and Zamboni, 1999). Utilizing space efficiently in the warehouse is also of increased significance when moving perishables since the temperature constraint of constant refrigeration provides a hefty expense. A special requirement for inventory management is the need to adopt a *first-in-first-out (FIFO)* or *first-expired-first-out (FEFO)* policy. Another common feature is strict directives for the handling process (Bartholdi and Hackman, 2019).

Food products and other perishables are very sensitive to temperature and other environmental conditions since the outcome of deterioration negatively affect the public's health. The additional constraints in cold chains add impact to some of the risks associated with supply chain management, including product traceability, transportation delays and breakdowns, cross-contamination in the transport and storage, and more (Chaudhuri et al., 2018). To this, there are often low margins in the industries and increasing concerns regarding waste (Göransson, Nilsson and Jevinger, 2018). Upon estimation, there is about 20-30 percent waste of perishables along the supply chain. A significant challenge considering food waste is one of the larger current environmental issues (Chaudhuri et al., 2018; Göransson, Nilsson and Jevinger, 2018). Ensuring quality and safety for perishables in the cold chains, and traceability and accessibility to product data in all stages of the supply chain are pressing issues emphasized in the world today (Chaudhuri et al., 2018).

3.2 Warehouse design and configuration

When it comes to design and configuration for warehouses, an important general guideline is to design the processes to maintain as continuous flow of goods as possible (Rouwenhorst et al., 2000). This entails avoiding pointless starts and stops, layouts that impede the flow, and searching for and resolve any bottlenecks (Bartholdi and Hackman, 2019). What purpose the warehouse serves is a determining factor when it comes to the flow characteristics and required operations. There are many resource and design aspects to consider in ensuring that the required operations are running as effectively and efficiently as possible. Prime examples of such aspects include the physical layout, storage and handling equipment, information systems, labor management, and automation solutions (Kembro and Norrman, 2020; Kembro, Norrman and Eriksson, 2018).

The design of a warehouse constitutes several interrelated decisions that must be made (Rouwenhorst et al., 2000). Gu, Goetschalckx and McGinnis (2010) consider five major decisions as determining the overall warehouse structure, constructing detailed department layouts, selecting operational strategies, equipment selection, and sizing and dimensioning of the warehouse and its departments. Where the overall warehouse structure regard determining the material flow pattern and relationships between departments. Detailed department layouts are the detailed configurations of a specific warehouse department e.g., aisle configuration of a retrieval area. Selecting operational strategy considers how the warehouse will operate regarding aspects such as order picking or storage decisions. Equipment selection means determining appropriate automation levels and equipment types e.g., storage, picking, and transportation. The last aspect, sizing and dimensioning of the warehouse and its departments, entail making decisions about the size and dimensions of the warehouse and the allocation of space amongst the departments.

When making decisions about the warehouse configuration it is crucial to have an appropriate understanding of the design and configuration goals (Kembro and Norrman, 2020; Kembro, Norrman and Eriksson, 2018). As discussed in the literature, the most significant configuration goals are deduced as being to reduce the lead time from customer order to shipment, increase space and resource utilization, increase total throughput, reduce material handling cost, and improve safety. To these goals, there are also some relating ones to consider, such as reducing the traveling distances, avoiding congestion, reducing administration, and increasing flexibility in terms of scaling up and down in capacity and handling of different products. It can be a complicated task to balance this since many of the configuration elements are interrelated. Just trying to focus on one element could lead to suboptimizations. Therefore, the configuration process often requires several iterations and trade-offs to be made. A top-down approach is recommended when selecting configuration, both to consider all relevant configuration aspects and for ensuring that fundamental choices are aptly made from the outset (Kembro and Norrman, 2020; Kembro, Norrman and Eriksson, 2018). Finally, once the design and configuration have been selected, it is important to evaluate its performance. This can be done in many ways and many different criteria or performance indices can be of significance, depending on the warehouse-type and its purpose. It is significant to do this to ensure that the performance is in tune with the configuration goals and the expected performance of the warehouse (Rouwenhorst et al., 2000).

3.2.1 Layout

Designing the warehouse layout includes configuring among other things the aisle characteristics, locations of departments such as the inbound and outbound, and managing space utilization (Bartholdi and Hackman, 2019). Depending on the specific purpose and configurational goals, the resource efficiency and throughput must be managed adequately. Because while the specific industry and purpose of a warehouse may vary, the layout configuration must always be able to manage the traditional challenge of balancing the storage and flow of goods (Bartholdi and Hackman, 2019; Kembro and Norrman, 2020). It is often a complex task to design the physical layout of a warehouse, as it requires many trade-offs and a thorough understanding of the warehouse’s objectives (Rouwenhorst et al., 2000). Many of the overbearing warehousing challenges typically have to do with the layout configuration, including managing traveling distance, utilization rates, and congestion (Bartholdi and Hackman, 2019).

Many warehouse configurations contain multiple departments, it could for instance be a forward-reserve area situation or different departments for different SKUs. These departments compete for space, which means that trade-offs to determine the dimensions of the warehouse and the space allocated to the different departments must be made (Gu, Goetschalckx and McGinnis, 2010). This is referred to as a *facility layout problem*, and it often accounts for activity relationships between the departments. Usually, the objective when managing this problem is to minimize handling costs, which typically in a warehouse translates into managing transports (de Koster, Le-Duc and Roodbergen, 2007).

According to Bartholdi and Hackman (2019), the layout of a warehouse determines the associated cost for each storage location. One of the most determinant factors of a layout configuration is the placement of the receiving and shipping areas. For which there are two general options to choose from, having the receiving and shipping areas located at opposite ends of the warehouse, a so-called *flow-through* configuration, or having both shipping and receiving on the same side, a so-called *u-flow*. Bartholdi and Hackman (2019) explain that there are advantages and disadvantages associated with both options, depending on the populations of SKUs moving through the warehouse. The flow-through configuration has all products moving in the same direction. The storage locations are of equal convenience, making it suitable for warehouses moving high volumes. A U-flow configuration makes convenient locations even more convenient and is fitting for a product assortment that complies with the 80-20 rule ("20 percent of the SKUs account for 80 percent of the activity") or is strongly ABC-skewed. ABC entails classification of SKUs as either A (the smaller most important fraction accounting for most of the activity), B (SKUs of second-tier importance), or C (the least important larger fraction of SKUs accounting for the smaller portion of the activity) depending on their impact on the total activity (Bartholdi and Hackman, 2019). Figure 9 from Bartholdi and Hackman (2019) illustrates the two alternatives, with the flow-through configuration to the left and u-flow to the right.

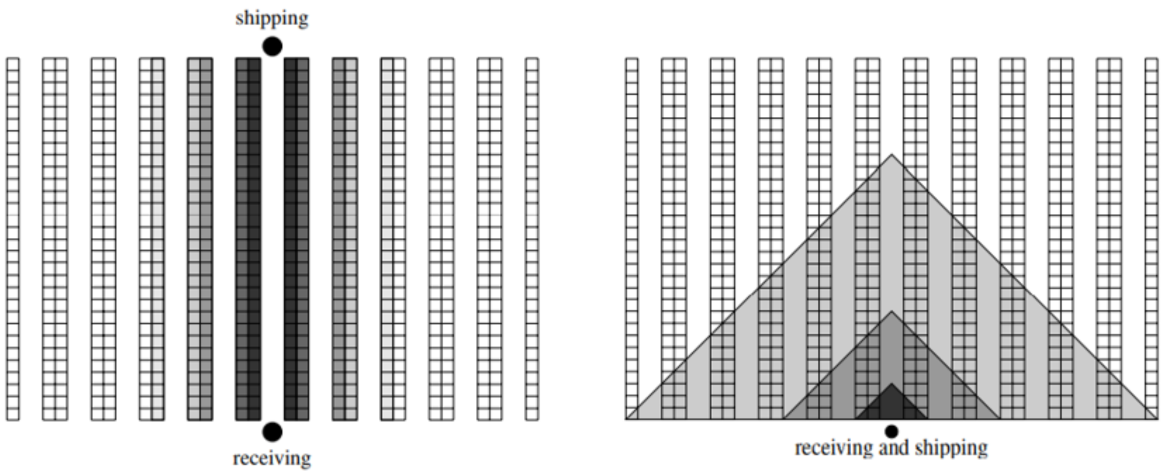


Figure 9. Flow-through and U-flow configurations (Bartholdi and Hackman, 2019)

Another aspect that must be dealt with when configuring a warehouse layout, is to determine the aisle structure. What can be called *internal layout design* or *aisle configuration problem* concerns the aisle orientation, the number of aisles, and their length and width (Gu, Goetschalckx and McGinnis, 2010; de Koster, Le-Duc and Roodbergen, 2007). The most suitable aisle configuration can be very situational. Bartholdi and Hackman (2019) recommend an approach that is suitable for a configuration where pickers are redirected to other storage locations before making drop-offs, namely *cross-aisles*, illustrated in Figure 10 to the left.

Another recommended approach, which may reduce traveling time significantly, though at the cost space, is the so-called *fishbone layout*, also illustrated in Figure 10.

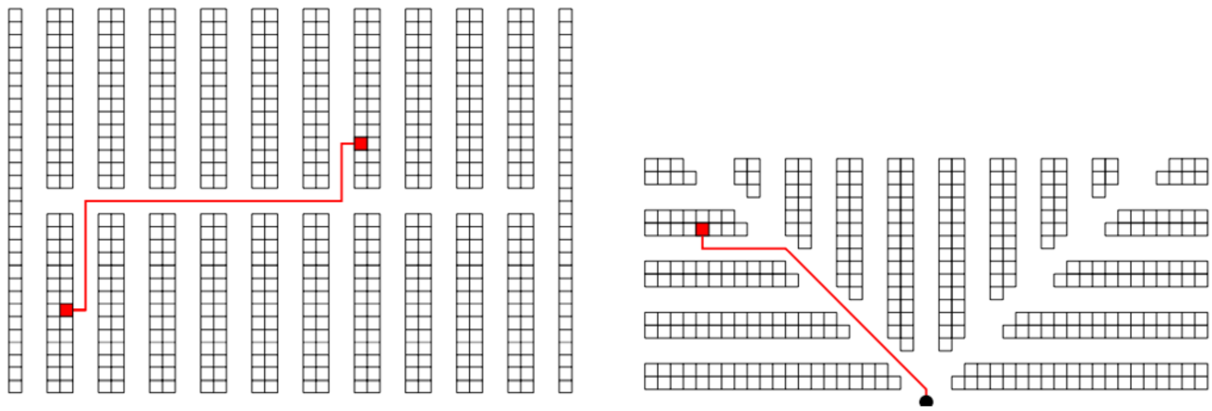


Figure 10. Cross-aisles and fishbone layout configurations (Bartholdi and Hackman, 2019)

3.2.2 Handling and storage equipment

Deciding on what handling and storage equipment to use in a warehouse is a strategic decision, as it affects all subsequent decisions about the configuration and the overall warehouse investment and performance. Equipment selection consists of two fundamental aspects, identifying feasible equipment alternatives for the storage and retrieval operations, and which one to choose from between these options (Gu, Goetschalckx and McGinnis, 2010; Baker and Canessa, 2009). There exist several equipment types that can help reduce labor costs and/or increase space utilization. For storage modes, it is common to use a pallet rack for bulk storage, a carton flow rack for more high-volume picking, and static shelving for low-volume picking (Bartholdi and Hackman, 2019). The simplest way of storing palletized products is to use floor storage, where it is common to arrange them in lanes of various *depth* i.e., the number of pallets stored back-to-back. Pallet racks are used for bulk storage or to support full-case picking. Storing the pallets in racks allows for better access to individual slots, stackability, and space utilization. There exist many types of rack storage, some of the most common ones, presented by Bartholdi and Hackman (2019), are:

- Selective rack (single deep rack) – stores pallets one deep, requires more aisle space to access pallets but does allow freedom to retrieve any individual one.
- Double deep rack – two single deep racks placed one behind the other, normally with this type of rack each lane is filled with one SKU to avoid the double handling, which in turn inevitably leads to some pallet locations being unoccupied.
- Push-back rack – essentially an extension to the double deep rack to fit additional pallet locations, where to make the interior slots accessible each lane pulls out like a drawer.
- Drive-In or drive-through rack – allows a lift truck to drive within the rack frame to access interior loads. This type of rack has pallets entering on one side and exiting on the other, allowing products to be moved in accordance with policies such as FIFO or FEFO. It does not however provide the same level of access flexibility to the pallets as the other racks do.
- Pallet flow rack – a deep lane rack in which the shelving is slanted, so when a pallet is removed the other gets pulled by gravity to the front. Appropriate for high-throughput facilities, this type of rack enables put-away to be on one side and retrieval on the other, thus preventing storage and retrieval operations to interfere with one another.

Bin shelving or static rack is the most simple and basic type of rack for storage in a warehouse, also the least expensive. However, these shelves are shallow, and any significant number of SKUs must be spread along the pick-face. This entails reduced SKU-density which tends to reduce the pick-density, thereby increase travel times, and reduce the number of picks/person-hour. With shelving picking and restocking must be made from the pick face. Gravity flow racks are a special type of shelving that is slanted and brings the SKUs forward for picking. It can store many SKUs in one small area of pick-face, which means a high SKU density and in turn higher pick density. The flow racks are restocked from the backside and do not interfere with the picking process, it does however require additional aisle space (Bartholdi and Hackman, 2019).

For handling equipment some type of lift truck is typically required to access the loads in the pallet racks, exceptions exist e.g., for *automated storage-and-retrieval systems (AS/RS)*. While some configuration of specialized racks may require specialized lift trucks, some of the more commonly used ones in warehouses according to Bartholdi and Hackman (2019) consist of:

- Counterbalanced lift truck – the most versatile type of lift truck but requires broad aisles and has height limitations.
- Reach and double-reach lift truck – equipped with a reach mechanism that allows forks to reach pallets, it is required to gain access to the rear position in double deep racks.
- Turret truck – has a turret that rotates 90 degrees to put-away or retrieve loads. This type of truck allows for very narrow aisles, but it only operates within single deep racks and is not easily maneuvered outside the rack.
- Stacker crane within an AS/RS – the handling component of a unit-load AS/RS, it has roof or floor-mounted tracks guiding the crane. It does not require much aisle width however each crane is often restricted to a single lane.

3.2.3 Automation

Automation can be used as a less expensive substitute for human labor (Bartholdi and Hackman, 2019). Various forms of automation have been used to an increasing extent over the last decades, with the intent to improve quality, performance, and efficiency in manufacturing industries (Tortorella, Narayanamurthy and Thurer, 2021). A case study by Kembro and Norrman (2020), showed that there has also been an increase in automation usage in warehouses, though to different extents. It is most common to apply automation solutions for the storage, picking, and packaging operations. Possible driving factors behind the seen increased usage could have to do with the increased need for sortation and packing, and ergonomics and safety. While the investment cost is high, it is expected to pay off and then some in the long haul, through streamlined flows and more cost-effective handling. It could also provide higher space capacity utilization in a warehouse, help reduce the overall lead time, allow real-time monitoring of inventory levels, and eliminate errors in the systems (Kembro and Norrman, 2020; Abhishek and Pratap, 2020; Custodio and Machado, 2020). A merger between the Lean philosophy and automation is gaining ground and is becoming an attractive approach to enhance performance and to manage the strain put on businesses (Tortorella, Narayanamurthy and Thurer, 2021). However, there are some important disadvantages with automation, such as the large investment costs but also that it is inflexible. It usually performs its intended purpose well, but if there are any business or configurational changes it could be very expensive to make the necessary adjustments. To justify automation for a warehouse it must run constantly to pay off the investment (Bartholdi and Hackman, 2019).

For a manual warehouse system, there is an order-picker driving a truck to picking locations, a so-called picker-to-parts system. A configuration with an automated warehouse system instead uses a parts-to-picker system (van den Berg and Zijm, 1999; de Koster, Le-Duc and

Roodbergen, 2007). An example of an automated solution is a *carousel*, which is a rotatable circuit of shelving used for storage and order-picking of small to medium-sized components (Bartholdi and Hackman, 2019). Here an order picker occupies a fixed position at the front of the carousel, upon which it rotates and arrives with the requested component (van den Berg and Zijm, 1999). There is also the AS/RS which uses aisle-bound cranes to retrieve units (Bartholdi and Hackman, 2019; van den Berg and Zijm, 1999; de Koster, Le-Duc and Roodbergen, 2007). Custodio and Machado (2020) describe the conventional AS/RS to consist of storage racks along aisles with unique or standard cell conveyors, *input/output (I/O)* stations for sending and receiving items, and for traveling within the aisles between the I/O stations and the storage cells is a mounted *storage/retrieval (S/R)* machine that transports pallets. To reach and access the storage cells a stacker crane is typically installed in the picking aisles to simultaneously travel in the vertical and horizontal direction. An AS/RS system can significantly improve the efficiency of storage, retrieval, and replenishment operations, but also the warehouse's flexibility and capability (Custodio and Machado, 2020; Bartholdi and Hackman, 2019). However, the recent trend of more e-commerce with large number of small orders composed of a variety of SKUs and items poses flexibility problems for these systems that handle full pallets. A possible solution for this is to have the ability for the AS/RS to travel cross-aisles allowing three-dimensional movement, to increase the flexibility of the AS/RS systems (Custodio and Machado, 2020). Hu and Chang (2010) propose such a solution by having an auto-access multilevel conveying device with three-dimensional movement integrated into the AS/RS. An illustration of this can be seen in Figure 11 where it moves cross-aisle along the X dimension and the picking aisle along the Y-Z dimension (Hu and Chang, 2010).

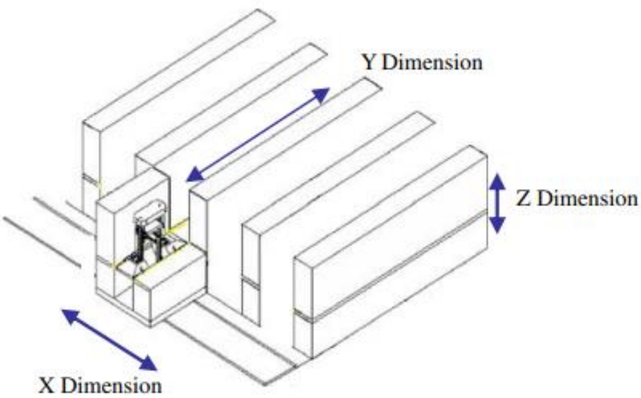


Figure 11. Example of AS/RS three-dimensional movement solution (Hu and Chang, 2010)

Bartholdi and Hackman (2019) also mention *A-frames* as a typical example of an automated solution in a warehouse. Used in instances with expensive labor and very high picking volumes, it is an automated dispensing machine that drops items upon a conveyor which deposits SKUs of one order into a box that is carried away by another conveyor. Beyond these examples, there is also the automatic warehouse system, which goes one step further by for instance replacing the picker in the scenario of the carousel with a robot. These types of automatic picking systems are applicable in instances with small to medium-sized non-fragile products, requiring high-speed picking (van den Berg and Zijm, 1999). There exist many more automation solutions for warehouses today than these examples and more are constantly being developed (Bartholdi and Hackman, 2019).

3.2.4 Information systems

Information systems can help manage the extensive set of activities in a warehouse (Rizzi and Zamboni, 1999; Gu, Goetschalckx and McGinnis, 2007). It exists many different information systems that can support warehouse operations (Kembro, Danielsson and Smajli, 2017; Rizzi and Zamboni, 1999). These systems could either be tailor-made for a specific warehouse or a standard software package (Faber, de Koster and Smidts, 2013). Before implementation of either system, it is important to clearly define the features of the warehouse configuration (Rizzi and Zamboni, 1999). The most frequently used systems are the ERP system, the WMS, and the *warehouse control system (WCS)*.

An ERP system is a common technology platform that integrates processes and shares information internally and externally i.e., both between different functions within an organization and between organizations (Kembro and Norrman, 2019; Kembro, Danielsson and Smajli, 2017; Faber, de Koster and Smidts, 2013). An ERP system can serve many functions, amongst which are inventory management, production planning, finances, and human resources. The planning horizon for an ERP system usually spans several weeks, covering most or all functions of an organization. A WMS in contrast has a short-term planning horizon and more specific functionalities linked to the warehouse operations (Kembro, Danielsson and Smajli, 2017). The WMS enables connectivity to ERP systems and is used for monitoring and handling warehouse resources and operations (Custodio and Machado, 2020). It registers incoming and outgoing SKUs and supports the tracking of inventory and orders flowing through the warehouse. Its functionality allows for a better overview of a warehouse and can reduce needed time to search for activities, reduce inventory and inventory variance, improve space utilization, and increase the service level (Kembro, Danielsson and Smajli, 2017; Kembro and Norrman, 2019).

The last common information technology used in warehouses is the WCS, which is used for controlling the flows of automation solutions, such as conveyors or robots. A related system also exists, *warehouse execution system (WES)*, which helps the synchronization of operations using both automation solutions and manual labor (Bartholdi and Hackman, 2019). The WES is the latest commercial distribution software, which purpose is to enable higher degrees of automation (Custodio and Machado, 2020). It can be viewed as an integrated version of the WMS and WCS. With all these information systems, there exist significant opportunities to save labor for a warehouse by achieving a better and more well-managed material flow (Bartholdi and Hackman, 2019).

3.2.5 Labor management

Managing a warehouse is all about space and time, that is labor or person-hours. Both space and time are costly, and the warehouse would therefore like to use as little of it as possible. A significant portion of the expenses in a warehouse is linked to labor. Where order-picking is usually the biggest contender, with most of its time devoted to traveling. One approach to reducing labor is storing products in convenient locations to reduce the traveling time. Another is to reduce deadheading through careful interleaving of put-away and retrieval, enabling trucks to travel directly to another pallet location after put-away (Bartholdi and Hackman, 2019). An approach that helps warehouse management is manpower planning. The workload in warehouses tends to fluctuate, some of which are predictable, and some not. These fluctuations can cause problems as it affects the scheduling of workers. Working with workforce scheduling is necessary to allocate the right workers to the right place and time. Insufficient workforce scheduling can imbalance the workload and lead to worker dissatisfaction (Dewi and Septiana, 2015).

According to de Leeuw and Wiers (2015) using flexible and temporary workers can help labor management. By flexible workers meaning fixed personnel with flexible contracts that allow employers to move them around to help better match the supply of labor with the demand. This allows for better utilization of personnel and more flexible planning. De Leeuw and Wiers

(2015) also mentions job rotation as a mean for this. Moving around employees and having them perform varying tasks, helps work stimulation and lowers absenteeism. Balancing the workload is another aspect mentioned to help improve a warehouse's performance. Where to even out the workload some orders that do not need to be performed on the indicative day are postponed, to help balance out the workload (de Leeuw and Wiers, 2015).

Another approach to labor management for instances where full-time and part-time shifts and moving workers around to balance the workload is insufficient is to construct an optimization model using linear programming as suggested by Popović et al. (2021). Where the model is used to reduce costs and freeing up capacity through better workforce utilization. The suggested model is apt as an approach for scheduling activities' execution together with workers to help face the variability. By setting up an objective function considering worker demand and cost, with necessary constraints such as working time, available shifts, activities, full-time/part-time workers ratio, breaks for workers, etc. the suggested algorithm by Popović et al. (2021) can make a schedule to better balance the workload, utilize resources and cut costs. This model can be applied when there is high demand variability that causes worker demand over one workday to fluctuate so that there is workflow surplus at times and shortage at others.

3.3 Factors influencing warehouse performance

To understand what factors influence a warehouse, it is important to create an activity profile. A warehouse activity profile is constructed through careful measurements and statistical analysis of the activities in a warehouse (Bartholdi and Hackman, 2019). By profiling the warehouse activities, a greater understanding of the operations is attained (Okeudo and Uche, 2013). Bartholdi and Hackman (2019) present some bullet points of key measures that can help to establish the activity profile, and that hints toward the economics of the warehouse:

- What are the business and industry? Who are the customers? What are the service requirements? What special handling is required (if any)?
- Types of storage, material handling equipment, and the area of the warehouse.
- The average number of SKUs in the warehouse.
- The average number of customer orders shipped per day.
- The average number of shipments received per day.
- The average rate of introducing new SKUs (assortment change).
- Demand trends or seasonality?
- The average number of order-lines/pick-lines shipped per day and the average number of units per pick-line.
- The number of order-pickers, and the number of shifts devoted to pallet movement, case-picking, and broken-case picking.

Activity profiling is a special case of data mining and a profile can be built based on data about the physical layout, stored SKUs, and customer order patterns (Bartholdi and Hackman, 2019). Having a comprehensive profile reveals characteristics that can help make decisions on storage and handling options. It comes especially in handy when analyzing activities for the purpose of determining storage mode, process workflow, facility layout options, and product slotting (Okeudo and Uche, 2013).

Gaining a thorough grip of what transpires in a warehouse is significant to understand what the contextual factors have for impact on the overall performance. It is widely accepted in literature that it is necessary to consider the environmental context, which for warehouse management refers to the immediate operating environment beyond the management control in the short run, or the external factors (Faber, de Koster and Smidts, 2013). There is an increase of attention towards the contingency approach, i.e., adjusting operations and design to fit a particular context, in the warehousing theory. The contingency approach suggests that organizations match their structure and processes to their environments to improve performance. It dictates that a lower performance is expected if there is a misfit between the warehouse configuration and the contingency factors (Kembro, Norrman and Eriksson, 2018; Kembro and Norrman, 2021). Impactful contextual factors to the design and operations, and thereby to a large extent the performance of a warehouse, includes the demand profile, order profile, product and process characteristics, and the warehouses' purpose (Kembro, Norrman and Eriksson, 2018; Faber, de Koster and Smidts, 2013; Eriksson, Norrman and Kembro, 2019). Further, product type and market predictability have an influence on supply chain control (Fisher 1997). To these contextual factors, there are also internal factors that influence the effectiveness and efficiency of a warehouse. These are connected to the configurational and design aspects of a warehouse and are the physical layout, the handling and storage equipment, automation solutions, information systems, and labor management (Kembro, Norrman and Eriksson, 2018). Table 7 presents some of the more prominent contextual and internal factors to a warehouse according to literature and provides a description for each one.

Table 7. Contextual factors in warehousing, adaptation from Kembro, Norrman and Eriksson (2018)

External factors	Description
Product profile	Held SKUs characteristics, dimensions, and type
Demand profile	Characteristics and size (volume) of current and forecasted demand, considering trends, seasonality, and demand variabilities for the different product portfolios
Order profile	The characteristics of placed orders, frequency and amount ordered (volume)
Purpose of warehouse	The type of warehouse and what purpose it is meant to fulfill
Internal factors	**Description**
Layout	The configuration of the warehouse, dimensions, and placement of e.g., equipment and storage
Handling and storage equipment	What racks, shelfs, trucks, etc. is used in the warehouse
Automation	Robots, conveyors, or other technology used to evade manual labor in the material handling
Information system	ERP, WMS or WCS used for coordination, and to process data and immaterial flows
Labor management	Scheduling, rotations, and shifts used to manage human resources

3.3.1 Warehouse operational performance

The performance of a warehouse configuration should, just like for any other business construct, be measured (Bartholdi and Hackman, 2019). With increasing complexity in the logistics networks, it is important to thoroughly assess and analyze performance to provide the most suitable design options (Staudt, et al., 2015). Simply measuring output is not sufficient when examining the performance of a warehouse. Just like many other functions, warehouses must be managed from a broader list of measurements, so-called KPIs (Bartholdi and Hackman, 2019). Depending on the industry and its requirements, the KPIs to choose from could vary.

Staudt et al. (2015) performed a literature review on operational performance measures for warehouses, in which they found that there are two types of measures *hard* and *soft* metrics. Hard metrics meaning quantitative measures and soft qualitative. Based on the frequency of occurrence in their extensive literature review, the outstanding KPIs for the quantitative measures consists of, in descending order from most frequently used: labor productivity, throughput, on-time delivery, order lead time, customer satisfaction, and inventory cost. The qualitative KPIs, which given their indistinct and vague nature, Staudt et al. (2015) grouped into seven indicator themes: labor, value-added logistics activities, inventory management, warehouse automation, customer perception, flexibility, and maintenance. The quantitative KPIs typically make up the basis for measuring a warehouses' performance, as the qualitative is more concept measures, making it difficult to obtain tangibles considering the amount of data required. The most significant KPIs for any warehouse are however difficult to determine. Since there is not always a consensus on the definitions of the KPIs and their respective boundaries (Staudt et al., 2015).

3.4 Lean

The core concept of Lean can be traced back to the 1980s to the *Toyota Production System (TPS)*, which is credited for coining the concept of JIT. It has its origin as a production practice, derived from the Japanese manufacturing industry, that aims to eliminate expenditure of wasteful resources, meaning activities that do not create any value for the end customer (Hallgren and Olhager, 2009; Arnheiter and Maleyeff, 2005; Gutierrez-Gutierrez, de Leeuw and Dubbers, 2016; Antony, Snee and Hoerl, 2017; Nepal, Yadav and Solanki, 2011). It can be described as an approach for redesigning production systems and for eliminating waste within the system (Näslund, 2013). The fundamentals of which still provide key elements to the Lean production and Lean management practices seen today (Arnheiter and Maleyeff, 2005). Many authors argue that today's Lean concepts are essentially just a repackaged version of the original JIT by TPS (Näslund, 2013). Nevertheless, Lean is seen as an approach that focuses on improving flow and process efficiency in the value stream, with an ultimate goal of achieving perfection, i.e., that all activities throughout provides value (Antony, Snee and Hoerl, 2017; Arnheiter and Maleyeff, 2005; Hallgren and Olhager, 2009). Depending on what level the concept of Lean is considered, the practice can be perceived as a philosophy (*strategic* level), a set of principles (*tactical* level), or a set of tools and practices (*operational* level) (Leksic, Stefanic and Veza, 2020).

Lean can be very apt in a warehousing context and result in important advantages to the processes and activities if applied properly (Villareal et al., 2012; Gunasekaran, Marri and Menci, 1999). It could result in substantial enhancements such as improved efficiency and efficacy, reduced processing times and lead times, and better inventory control. Abushaikha, Salhieh and Towers (2018) found in their study that reducing wastes has a positive impact on warehouses' operational and distribution performance. Improved warehouse operational performance indicated higher achieved business performance for the organization. Amongst the vast set of tools and techniques in the practice, material flow analysis, *5S*, *Kanban*, visual management, *standard operating procedures (SOP)*, and *value stream mapping (VSM)*, are all especially viable for improving warehouse performance. A key technique for reducing the non-value adding steps and making significant improvements is the VSM. It is an important first step towards obtaining a Lean warehouse and it was found in a case study that after implementation it reduced processing time by half and lead time one-fourth (Abhishek and Pratap, 2020; Martins et al., 2020). More on the tools and techniques are explored in the upcoming subsection. The Lean application in a warehousing setting is however still a somewhat unexplored area but is in full development today (Villareal et al., 2012).

3.4.1 The seven wastes

Improved operational performance by implementing Lean, has been substantially researched and confirmed by literature (Abushaikha, Salhieh and Towers, 2018). Practicing Lean means applying Lean thinking, to which there are five principles to adhere to 1) value is defined from the customer perspective, 2) identify the value stream, 3) flow is about ensuring value-creating activity's flow, 4) customer pulled-value (using a pull schedule), and 5) pursuit of perfection (Nepal, Yadav and Solanki, Hallgren and Olhager, 2009; 2011; Martins et al., 2020). This entails reducing waste, or *muda*, through continuous improvements or *kaizen* events (Arnheiter and Maleyeff, 2005; Azevedo et al., 2019). Lean can be viewed as a systematic approach for eliminating all sources of inefficiencies in a value chain, to narrow the gap between actual performance and the customer and shareholder demands (Asmae et al., 2019; Azevedo et al., 2019). Where inefficiencies refer to the seven commonly accepted wastes in TPS (Hines and Rich, 1997) displayed in Table 8, an additional eighth one is sometimes added to these *not utilizing talent*. These wastes refer to everything that adds cost but does not contribute value to the end customer (Asmae et al., 2019). Since the seven wastes are coined to fit a manufacturing context, Abushaikha, Salhieh and Towers (2018) and Abhishek and Pratap (2020) translated them to better fit the warehousing environment, also presented in Table 8.

Table 8. The seven wastes, compiled adaptation from Hines and Rich (1997), Asmae et al. (2020), Melton (2005), Abushaikha, Salhieh and Towers (2018), and Abhishek and Pratap (2020)

Waste	Meaning (manufacturing)	Meaning (warehousing)
Overproduction	Producing more or earlier than demanded	Picking or preparing orders before being ordered downstream (congestion)
Waiting	Whenever goods are not moving or being worked on	Inefficient time usage leading to stoppage of inventory movement or a period of inactivity
Needless transport	Transportation without real utility (non-value adding movement of goods)	Transportation without real utility
Inappropriate processing	Process step which does not produce (contribute) any value	Process step which does not contribute any value (double actions)
Redundant stock	Storing greater quantities than needed for the subsequent step	Overproduction upstream leading to excess stock; Storing safety or buffer stock in the warehouse
Needless motion	Performing unnecessary movement for work execution	Worker making redundant actions which are avoidable
Defects	Errors during process that either requires re-work or additional work	Dispatched orders that do not conform to requirement

3.4.2 Practices and tools

To achieve the Lean management goal of eliminating all non-value adding activities (or wastes), and optimizing quality, cost, and delivery time, whilst maintaining worker safety, it is essential to focus on the three main culprits of inefficiencies in any operational process, wastage, variability, and lacking flexibility (Näslund, 2013; Asmae et al., 2019). To accomplish this, Lean relies on standardized working procedures combined with an extensive set of tools and techniques. Amongst the over one hundred counted Lean management tools or practices, some of the more important and prominent ones are: 5S, Kaizen, Kanban, *Plan-do-check-act (PDCA), poka yoke, root cause analysis,* and VSM (Leksic, Stefanic and Veza, 2020; Melton, 2005;

Gutierrez-Gutierrez, de Leeuw and Dubbers, 2016). The following provides a brief description of these practices, excluding VSM which gets its own subsection.

ASQ (2021) describes 5S as a methodology that can be applied to reduce waste and improve productivity. It helps build a better work environment, both physically and mentally. It is in its core a quality tool and is derived from five Japanese terms beginning with the letter "S", a description of each is featured in Table 9. Applying 5S to a system leads to increased process standardization and a more organized workplace, which can result in waste reduction (EL-Khalil, Leffakis and Hong, 2020; Dresch et al., 2019; ASQ, 2021).

Table 9. The 5S methodology with definitions, adaptation from ASQ (2021)

Original	Translation	Definition
Seiri	Sort	Eliminating unnecessities by removing tools, parts, and instructions from obsolete material
Seiton	Set in order	Organize what remains by arranging and identifying parts and tools for ease of use
Seiso	Shine	Tidy up workplace area by using cleaning campaigns
Seiketsu	Standardized	Perform *Seiri*, *Seiton*, and *Seiso* daily by scheduling regular cleaning and maintenance
Shitsuke	Sustain	Make the first four S's a habit and way of life to ensure the success of improvements using 5S

Kaizen entails continuous improvements, which in a Lean context is a strategy in which employees work together to regularly achieve improvements to a process. Kanban is a "pull system", meaning an approach where the material is sent to subsequent operation after signaled request (Leksic, Stefanic and Veza, 2020; Dresch et al., 2019; ASQ, 2021a). PDCA is a project planning tool consisting of four phases, Plan, Do (perform), Check (monitor), and Act (improve). It is an iterative procedure that can be used to make continuous improvements (ASQ, 2021b; EL-Khalil, Leffakis and Hong, 2020). An illustration of the PDCA cycle can be seen in Figure 12.

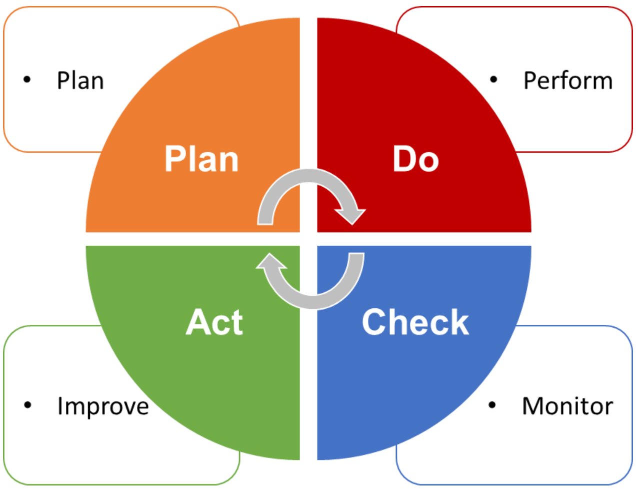


Figure 12. The PDCA cycle (ASQ, 2021b)

Root cause analysis or *5 Why* is a quality tool featured in the extensive Lean toolbox that is used to analyze the root cause of any problem. It is an iterative approach for exploring cause-and-effect relationships. The aim of the technique is to determine the root cause by repeatedly asking the question "why?" until a satisfying outcome is reached (ASQ, 2021c). Mistake-proofing or poka yoke, is a practice that induces more stability in a process (EL-Khalil, Leffakis and Hong, 2020). It is a common process analysis approach for making an error impossible to occur or immediately visible and obvious (Dresch et al., 2019; ASQ, 2021d). In its essence, it is a tool that can be used to prevent failures (Dresch et al., 2019). There is a five-step procedure for mistake-proofing, as presented by ASQ (2021d):

1. Obtain a flow chart of the investigated process. Review the steps and consider where human errors may occur.
2. For each of the potential errors, try to find the source.
3. For each of the potential errors, think of ways to make it impossible to occur. Consider elimination (removing the step), replacement (replacing the step with an error-proof one), and facilitation (make the correct action significantly easier than the incorrect one).
4. If the errors cannot be made impossible to occur, think of ways to make it easier to detect and minimize its impact.
5. Choose the best mistake-proofing method and implement it. Then successively follow it up.

Another common Lean process analysis tool is the Spaghetti diagram. The Spaghetti diagram can be used to provide a visual representation of the pathing of an item or activity through a process (ASQ, 2021e). It can be used to identify movement patterns in a work area (Bhat et al., 2016), an example of which can be seen in Figure 13.

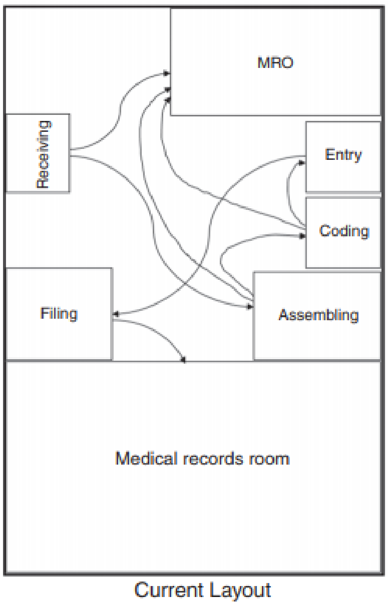


Figure 13. An example of a Spaghetti diagram of a medical records department work area (Bhat et al., 2016)

3.4.3 Value Stream Mapping

One of the most recommended approaches for improving processes by identifying wastes is value stream mapping (Villareal et al., 2012). It is one of the many tools within the extensive Lean toolkit and is used for making continuous improvements to a system by identifying value-adding and non-value-adding activities and successively removing the wastes (Leksic, Stefanic and Veza, 2020; Nepal, Yadav and Solanki, 2011; Yilmaz, Ozcelik and Yeni, 2020). VSM is a proven technique and one of the most widely employed visual tools (Yilmaz, Ozcelik and Yeni, 2020). It is also flexible, in the sense that it can be applied on various levels. On a high strategic level, it can be used to provide overall guidance for waste reduction to the lower levels who apply it more functionally and at a smaller scale. VSM is also applicable for the single organization as well as cross-organizationally for supply chains and can be applied to reduce wastes in transportation processes, among other areas (Villareal et al., 2012). Applying techniques that consider the bigger picture of value streams to remove wastes, arguably realize more benefits than those focusing on induvial systems, which run the risk of creating suboptimizations (Brunt, 2000).

VSM consists of two main steps current state, and future state mapping (Yilmaz, Ozcelik and Yeni, 2020). Before mapping the current value stream for any process, it is important to clearly determine what "value" constitutes for that process. Taking into consideration the processes' objectives and the role each activity has in satisfying the customers' requirements (Nepal, Yadav and Solanki, 2011). It is also important to determine the process or product families beforehand (Brunt, 2000). When mapping the current state, the goal is to visualize the as-is state of material and immaterial flow in the investigated system. Several Lean techniques and tools are applied to reduce or eliminate any identified inefficiencies or wastes in the process, to reach the future state map, which is a visualization of the intended future state (Yilmaz, Ozcelik and Yeni, 2020).

Determining process families is the first major step in the VSM process, and entails grouping products or services into a process or product family based on them going through the same or similar process steps. The reason for this grouping is that it often becomes too inconvenient or impractical to map out all the products moving through the processes. There are tools that can help the grouping, one of which is applying a process family matrix. From which patterns or similarities between products can be identified. Having identified the process families, a decision on which ones to focus first must be made. There are several criteria that could be a determining factor, for instance, it could be based on volume or quantity, the biggest impact to the customer, or the biggest "bang for buck" (ASQ, 2021f).

Having determined the process families, construction of the current state map can begin. This map features a visualization of the current information, documentation, and material flows in the investigated system (Yilmaz, Ozcelik and Yeni, 2020). It presents both the value and non-value adding activities and typically highlights symptoms of waste such as waiting, needless movement, inventory, rework, transports, or erroneous processes (Simonsson, et al., 2012). When constructing the map, the first thing to consider and determine are the boundaries of the investigated process, including where it starts and finishes. Typically, the current state map is created by collecting data by using a process activity map and "walking the flow" i.e., interviewing people performing the tasks along with the process steps (Brunt, 2000; ASQ, 2021f). The gathered data may include cycle times, changeover times, quantities, number of operators and shifts, etc. the gathered Information does not have to be overly detailed, but rather present an overall picture of the system (ASQ, 2021f). Once enough data is gathered, the actual drawing of the current state map can start. There exists a baseline of standard typical shapes used for drawing up the map, some of which can be seen in Figure 14. There are four distinct stages that generally need adhering to when drawing the map, these are details about the customer's requirements, marking the details about the physical flows, mapping supply of materials, and mapping the information flow. Once done, the final step is to draw up a timeline at the bottom, showing the total amount of time of value-adding process and non-value adding processes to a product (Brunt, 2000). No VSM will look fully alike, there will always be slight differences depending on the process's nature and how it is drawn (ASQ, 2021f).

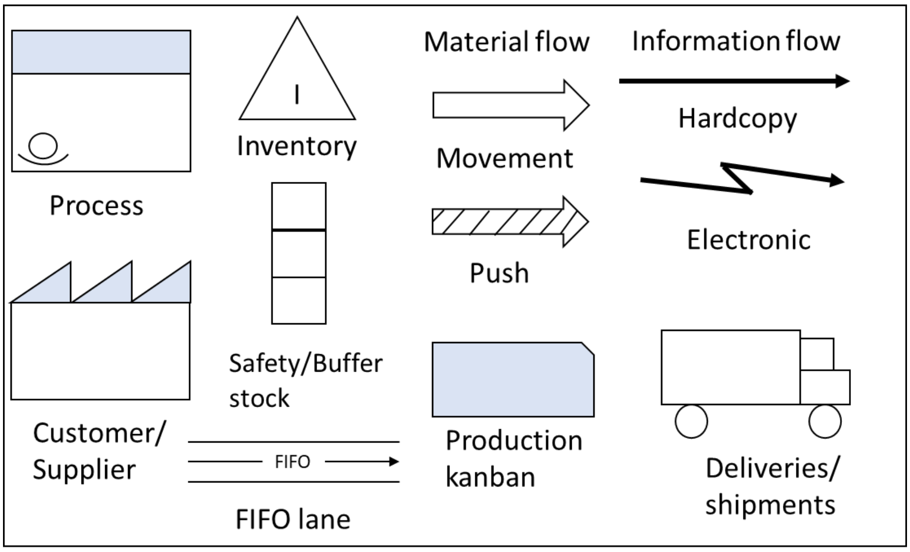


Figure 14. Typical VSM symbols, adaptation from ASQ (2021f)

With a finished current state map, the final major step of the VSM procedure, the future state map, can start. The future state map brings out the true potential of the VSM approach, which is the developed vision for how good the value stream for the product(s) can be and a plan on how to reach that stage (Brunt, 2000; Simonsson, et al., 2012). When drafting up a future state map there are a few approaches that can be useful to apply, such as producing the *takt* time. The takt time refers to how frequently the product must be produced and/or distributed to meet the customer demand and can be estimated by dividing available time per shift by the demand per shift. This determined takt time can then be used to identify bottlenecks or constraints in the process. Another approach is to examine where inventories can be reduced or even removed in a logical manner. Trying to make the flow more continuous is an important aspect when constructing the future state map, searching for any unnecessary areas where the material is stopped and waits, and trying to eliminate this. Other miscellaneous improvements to the system are lastly considered, which could for instance regard new and improved equipment, layout and configurational changes, standardization of work procedures, and implementation of other techniques such as 5S (ASQ, 2021f).

The transition to the future state configuration will, once achieved, provide significant benefits with more efficient processes through the reduction of wastes (Brunt, 2000). This transition may however be challenging and will require a concrete plan containing clear steps towards reaching the future state. A plan which will typically require refinements along the way, and one that should contain and clearly specify deliverables, cost estimates, performance impacts, overall goals, and the benefits of making the alterations (ASQ, 2021f).

3.4.4 Achieving strategic fit

Lean is an efficiency-oriented change initiative, for it to be successful in implementation it must be fitted with the organization's competitive strategy (Näslund, 2013; Chopra and Meindl, 2007). A company's competitive strategy is the means through which it seeks to satisfy customer needs with its goods or services. All functions of a company play a role to execute the competitive strategy, and each must in turn create its own strategy to fulfill its part. Chopra and Meindl (2007) state that it is crucial that all functions are strategically aligned and that there exists a close relationship between them. Strategies cannot be formed in isolation but in unison. Any function that plays a part in an organization's value chain contributes to the overall success or failure. One single function cannot ensure the success of the whole chain. The success or failure rate of any company comes down to its ability to have competitive and functional strategies fitted to form a coordinated overall strategy; that each function follows through and structures its resources to execute that strategy; and that the overall supply chain and each stage supports the entire supply chain strategy (Chopra and Meindl, 2007).

So, what is the right supply chain for the products? That is a question explored by Fisher (1997), and it essentially boils down to two overall strategies to choose between cost-efficient or market-responsive. Where the former is strategically fitted for functional products and embeds traits for having the primary strategic purpose of achieving the lowest possible cost, in alignment with the Lean philosophy (Fisher, 1997; Gutierrez-Gutierrez, de Leeuw and Dubbers, 2016). This entails that all functions have high utilization rates, high inventory turns and low stock levels, and short lead times. The latter strategy, market-responsiveness, is suited for innovative products and is accompanied by a strategy that includes having quick response to unpredictable demand, flexible scalability, excess buffer capacity to never reach stockouts, and postponement strategies for manufacturing. A company might fail if they lack a strategic fit or its supply chain design, processes, and resources do not support it (Chopra and Meindl, 2007; Fisher, 1997).

Chopra and Meindl (2007) explain that achieving strategic fit between supply chain and competitive strategy comes down to three steps. The first one is to understand the customer and supply chain uncertainty. Uncertainty can be mapped out on an implied uncertainty spectrum, ranging from predictable supply and demand e.g., salt, to high uncertainty e.g., a new communication device. After understanding the implied uncertainty, the second step is to understand the supply chain capabilities. Where the question of how the firm best meets the demand is raised. Responsiveness comes at a cost, for every strategic choice made to increase responsiveness there are typically costs that lower the efficiency. Copra and Meindl (2007) present a *cost-responsiveness efficient frontier*, an adaptation of which is illustrated in Figure 15, where the frontier represents the cost-responsiveness performance of the best supply chains. A firm that is not located on the frontier can improve both responsiveness and cost performance by moving towards it. The last step, after understanding the supply chain's position on the responsiveness spectrum, is ensuring that the extent of supply chain responsiveness is in tune with the implied uncertainty. High responsiveness is desirable when there is high implied uncertainty, and in turn, high efficiency is apt when there is low implied uncertainty. It is important for companies to reach a satisfying position in the zone of strategic fit regarding implied uncertainty and responsiveness level. All functional strategies in any firm must support and be aligned with the supply chain's level of responsiveness to have a successful competitive strategy.

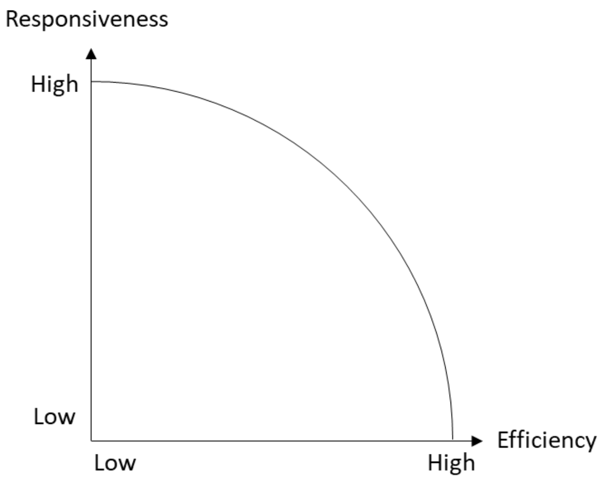


Figure 15. Cost-responsiveness efficient frontier, adaptation from Chopra and Meindl (2007)

3.4.5 Critical success factors

Organizations must continuously change and adapt to meet the external demands of the dynamic business environment (Knapp, 2015). When considering implementing the Lean principles, it is important to ensure for full effect that all entities, including warehouses, in the supply chain supports and practices it (Abhishek and Pratap, 2020). Successful implementation of Lean normally provides clear benefits to the organization's processes. However, as with the implementation of any change initiative, forces are working against it, and some critical success factors need adhering to (Melton, 2005; Näslund, 2013). Critical success factors are referred to as key areas required to function adequately to ensure successful competitive performance for an organization (Leidecker and Bruno, 1984). If the intent and purpose are apt, and the change initiative is strategically aligned with the organization's competitive strategy, implementing Lean is more likely to provide a satisfying outcome (Näslund, 2013).

Dervitsiotis (1998) argues that three major forces driving organizational change dissatisfaction with current performance level, attraction towards more desirable conditions, and appeal of the change strategy. If any of these are absent, there will not be any motivation from management to bring about organizational change. It is therefore argued that management commitment and involvement are vital for a change process to succeed (Dervitsiotis, 1998). Top management support and organizational culture are typically significant factors for success for businesses (Knol et al., 2018; Näslund 2013; Melton, 2005). A literature review on success factors for implementing Lean practices in manufacturing *large enterprises (LEs)* and *small and medium-sized enterprises (SMEs)* was conducted by Knol et al. (2018). This study merged and compiled twelve identified critical success factors from the literature. Found was that the most common success factors in literature are top management support, improvement training, and performance management system. However, after conducting a Necessary Condition Analysis regarding the twelve critical success factors found in literature on 33 Dutch manufacturing SMEs, Knol et al. (2018) found that communication, a learning focus, an improvement structure, and support congruence was the most important factors in the initial stages of implementing Lean. It is argued though that there may be a sequence in which factors become critical for success. Some factors may be critical for organizations in the initial stages of implementing Lean practices, and some only seemingly critical for organizations that have become advanced Lean practitioners (Knol et al., 2018). Something that coincides with what Näslund (2013) states regarding that there are some slight variations and that the critical success factors for an organization relate to how the change effort is approached.

One of the biggest challenges and resisting forces to Lean is people's resistance to change (Näslund, 2013; Melton, 2005). A found issue by Pepper and Spedding (2010) is that employees might fear layoffs associated with the implementation of Lean practices, because of cost reduction programs and aims of higher employee efficiency. Hines et al. (2004) describe that there have been some criticisms towards Lean programs as being exploitative and dehumanizing of workers. Although it is noted that such criticism has gained limited support, they argue the importance of considering human aspects such as motivation and empowerment. In the long haul, Brkic and Tomic (2016) found that the change initiative positively influences metrics such as employee satisfaction and commitment, absenteeism, salaries, and turnover rate. This indicates that although people's initial perception might be negative, the employees will later experience the benefits of it and gradually become more positive (Brkic and Tomic, 2016). By implementing a concept such as Lean the status quo is challenged, however with the right intent, the forces supporting Lean should outweigh those resisting (Melton, 2005). Figure 16 provides an illustration of the opposing forces towards being Lean.

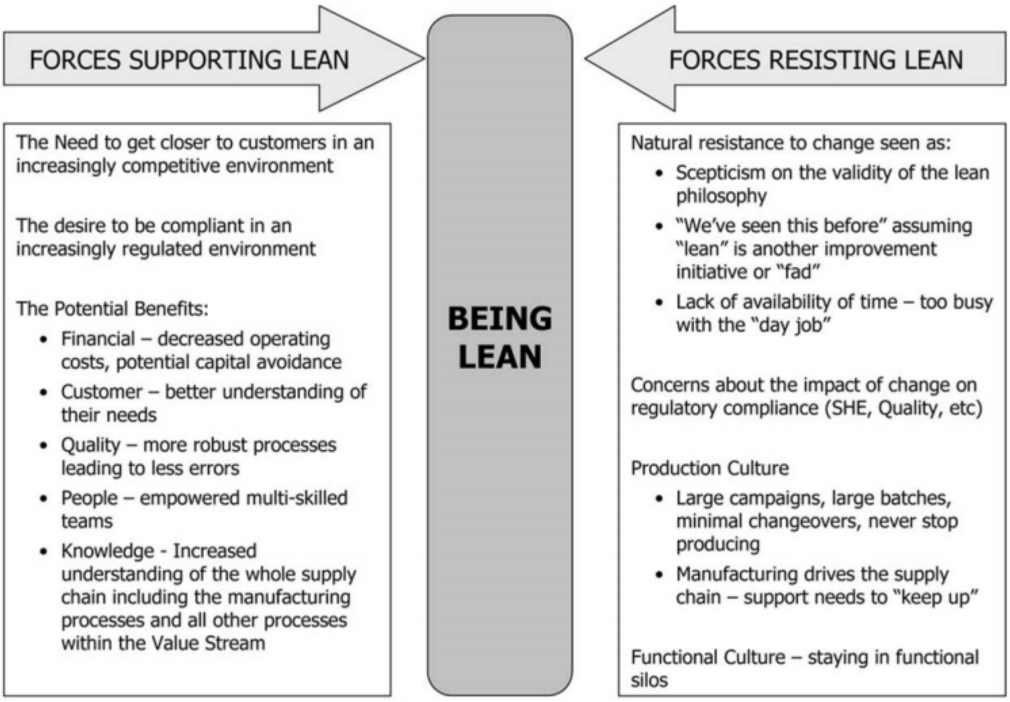


Figure 16. Opposing forces to Lean (Melton, 2005)

Following the Lean philosophy entail pursuing reduced lead times, delivery times, inventory, set up times, downtime, quality uncertainties, scrap, rework, and other wastes (Gutierrez-Gutierrez, de Leeuw and Dubbers, 2016). This makes the concept more apt for certain types of industries. Consider the product-process matrix by Hayes and Wheelwright (1979) as a baseline, although intended for the strategic role of a manufacturing function, Lean becomes applicable first at stage 3 (Jain, Adil and Ananthakumar, 2013). Thus, making it an applicable strategy for efficiently oriented industries and supply chains, as the adaptation from Hayes and Wheelwright (1979) in Figure 17 indicate. It is appropriate for organizations with high production volumes that experiences low degrees of customization in the processes and low demand variability (Näslund, 2013). An example of this is the automotive industry, and therein referring to functional cars and not the innovative exclusive ones (Fisher, 1997; Jain, Adil and Ananthakumar, 2013).

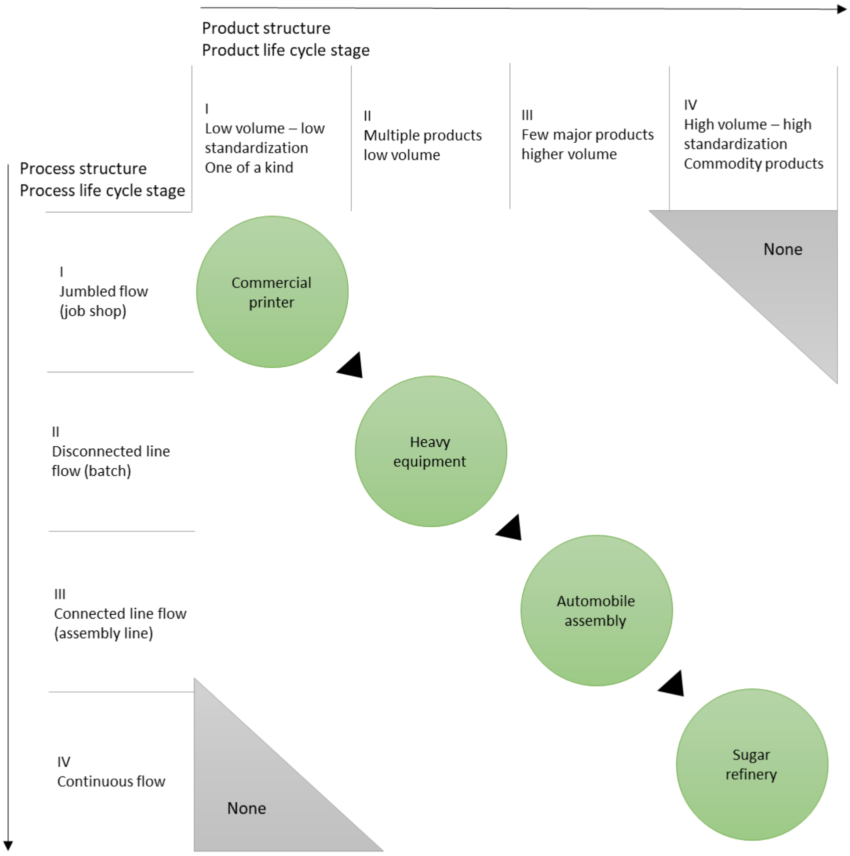


Figure 17. Product-process matrix (Hayes and Wheelwright, 1979)

3.5 Framework for analysis

The framework for analysis constitutes the connection and linkage between the frame of reference findings, empirical findings, and analysis from the conducted study and how it connects to the research objectives. A visualization of the connections can be seen in Figure 18. The figure illustrates that the frame of reference provides inputs to both the empirical findings section and the analysis section, and how the progression of the research is formed, leading up to fulfillment of the research objectives and provided final recommendations.

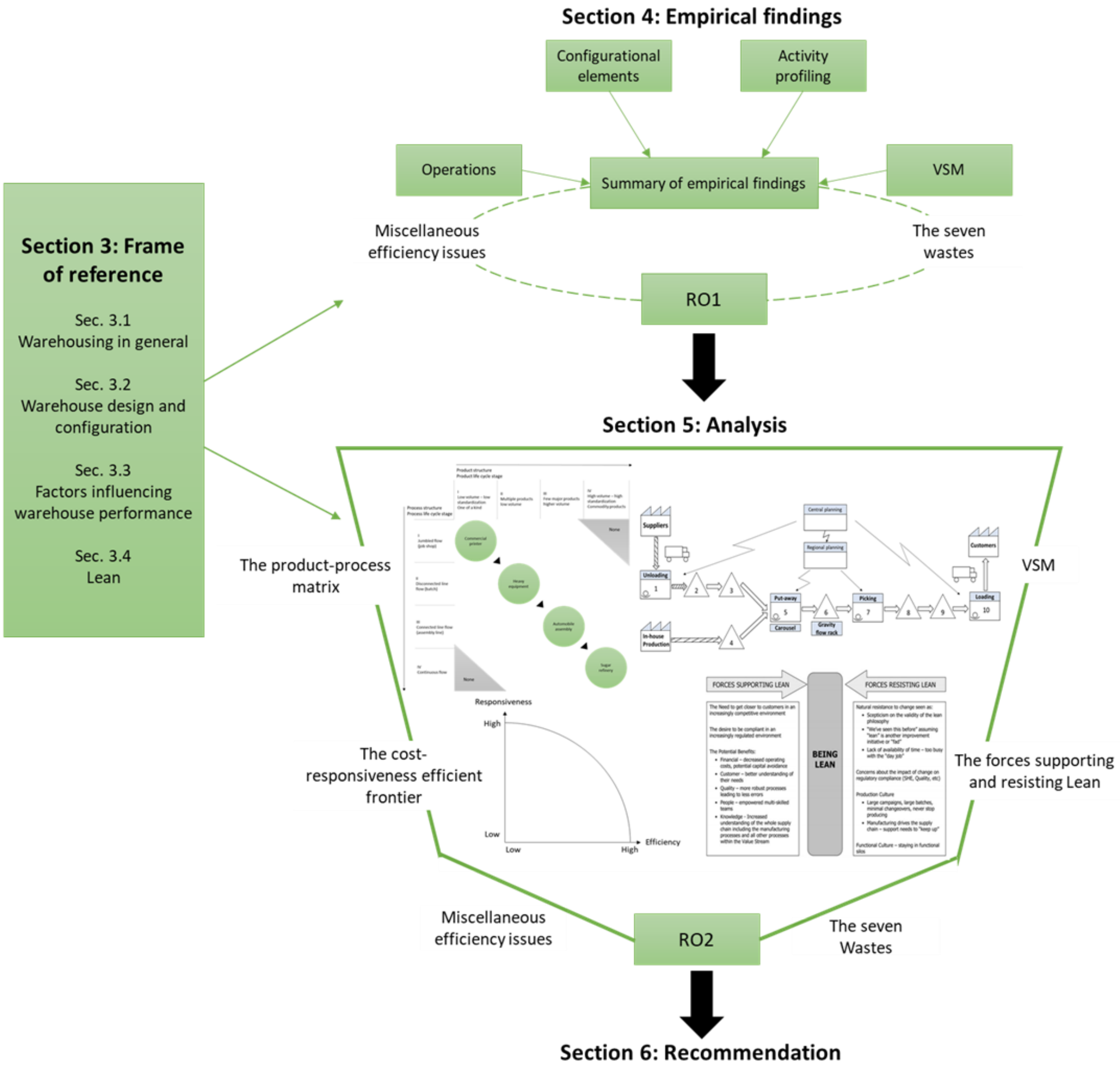


Figure 18. Visualization of the framework for analysis

The first research objective (RO1) considers the current state problems of the case company warehouse and is accomplished in the empirical findings through investigating areas highlighted in the literature findings, as indicated by Figure 18. These areas consist of the warehouse operations, the warehouse design and configurational elements, mapping of the material flow channels using VSM practice, profiling the warehouse activity, and finally compiling the findings. Accordingly, the literature dictates that the fundamentals for a warehouse to fulfill its purpose lies in its operations. The initial step before any problems can truly be identified is to gain an understanding of the warehouse's purpose and the operations that make out the processes from inbound to outbound. Followed by an understanding of the warehouse's current configuration and configurational goals. Knowing how to prioritize the configurational elements and how they are currently balanced in the warehouse will be significant when later making suggestions about configurational changes. Common design and configurational aspects that must be balanced considered in any warehouse were according to literature the layout, handling and storage equipment, automation, information system, and labor management.

Activity profiling was emphasized as a prominent means to understand what fully transpires in a warehouse. An activity profile of the investigated warehouse is thus performed, where the mentioned key basic statistics in the frame of reference are gathered. With this knowledge baseline, the material flow processes can be mapped out and investigated to search for problems. VSM is an acclaimed approach for getting a grip on reality and finding problem areas in a process. Said approach is therefore applied at the case company to provide full coverage for the objectives. To finally achieve the first research objective, as Figure 18 shows, the findings are summarized in terms of wastes accordingly with the definitions provided in the section about Lean, and as other miscellaneous efficiency-related problems identified through mapping out the current state and profiling the warehouse activity.

Having identified the efficiency-related problem areas in the warehouse, the study progresses to the analysis section and the second research objective (RO2), developing remedies for the issues. RO2 is processed in the analysis section as illustrated by Figure 18, where to satisfy the objective, the empirical findings are put in relation to the literature findings. The literary findings describe the general warehouse and the nature of the perishables industry. It further explains typical means on how to manage and balance the configurational elements of any warehouse. These perspectives in the light of the empirical findings are used for analyzing how to salvage the current state problems. Accompanied by the activity profiling findings and the contextual factors impact and relevance to the case. Under the warehouse operational performance section, the significance of smooth well-managed material flows throughout the supply chain is emphasized, and how the concept of Lean can be applied to reduce disruptions and serve as a guiding tool for improving an organization. The section on Lean emphasized certain principles that should be adhered to, wastes that must be reduced, and which businesses benefit from applying a Lean thinking mentality.

With the influencing aspects presented in the frame of reference, the analysis section in which to generate remedies to the efficiency problems begins. Using the VSM as a primary tool for the analysis, the Lean mindset is applied when constructing the future state map and making the final recommendations to the case company warehouse, bearing in mind the forces supporting and resisting Lean. Focus accordingly lies in reducing the wastes in the system. To ensure that the right orientation for the case company organization is considered before making any suggestions, the product-process matrix by Hayes and Wheelwright (1979) is used to visualize how potential remedies will impact the case company warehouse's placement in relation to the desired diagonal. Together with the also significant objective of achieving strategic fit and alignment in terms of cost-efficiency contra responsiveness, considering the Chopra and Meindl (2007) cost-responsiveness efficient frontier. Once desired orientation for the remedies is understood, any generated remedy options that drive in that direction are considered for the final recommendation and the fulfilling of RO2. Solutions to the wastes and miscellaneous efficiency issues in the warehouse are thereby compiled into a final set of recommendations. Sensitivity and feasibility aspects are then finally reviewed, to ensure reasonable improvement suggestions are provided to the case company warehouse.

4 Empirical findings

This section presents the empirical findings from the conducted study. The section is divided into four fragments, starting with findings about the warehouse configuration, with data derived from interviews and observations. This is followed by mapping of the warehouse's current state, compliant to VSM practice. The third part presents an activity profile of the warehouse, compiling key data about the flow of goods from the case company's information systems. These three subsections are compiled in the fourth fragment, which presents key identified problems that hinders efficiency and thereby satisfy the first research objective of the study.

4.1 Warehouse configuration

To reiterate, the investigated case company is Arla Foods AB, more specifically the cold storage warehouse facility located in Jönköping, Sweden. This warehouse is by definition a *distribution warehouse*, it contains no refining process other than the consolidation and distribution of goods. Mainly Arla branded goods are moved through the warehouse, which either stems from the in-house production unit or another Arla subsidiary, along with some other goods that are also moving through Arla's distribution network. The warehouse itself has three main material flow channels, through which a major portion of the goods passes through. Being in the perishables industry, Arla has pressing demand to keep short lead times and high product quality. The most significant performance indicators for the warehouse are the on-time delivery to bay, accompanied by safety measured in *Lost Time Accident (LTA)* per year, complaints measured in *backorder cost*, and space utilization since keeping a constant temperature of 4°C is costly. This case study focuses on the efficiency of the warehouse and attempts to suggest improvements to the primary flow channels. The following part will start by presenting the key findings about the configurational elements of the warehouse, data for each section is based on gathered qualitative data, predominantly from the interviews.

4.1.1 Layout

The physical layout of the warehouse follows the overall logic of a *flow-through* configuration structure, by having the inbound and internal production unit located in one end of the warehouse in its northern part, and the outbound area located on the opposite end in the southern part. This is showcased in Figure 19 which is derived from blueprints of the case company warehouse layout. The inbound section of the warehouse has eight docks for receiving and 25 gates that are connected between the warehouse facility and the internal production unit via a conveyor system. The outbound section constitutes 21 bays or loading docks, essentially covering the entire southern length of the facility. Moving from one end to the other the goods travel through one of three main material flow channels, with only a few exceptions. These three flows are in a sense divided into three picking zones, into which goods are diverted dependent on their product characteristics and SKU. The three main flow channels go under the names fine picking, tets, and crates.

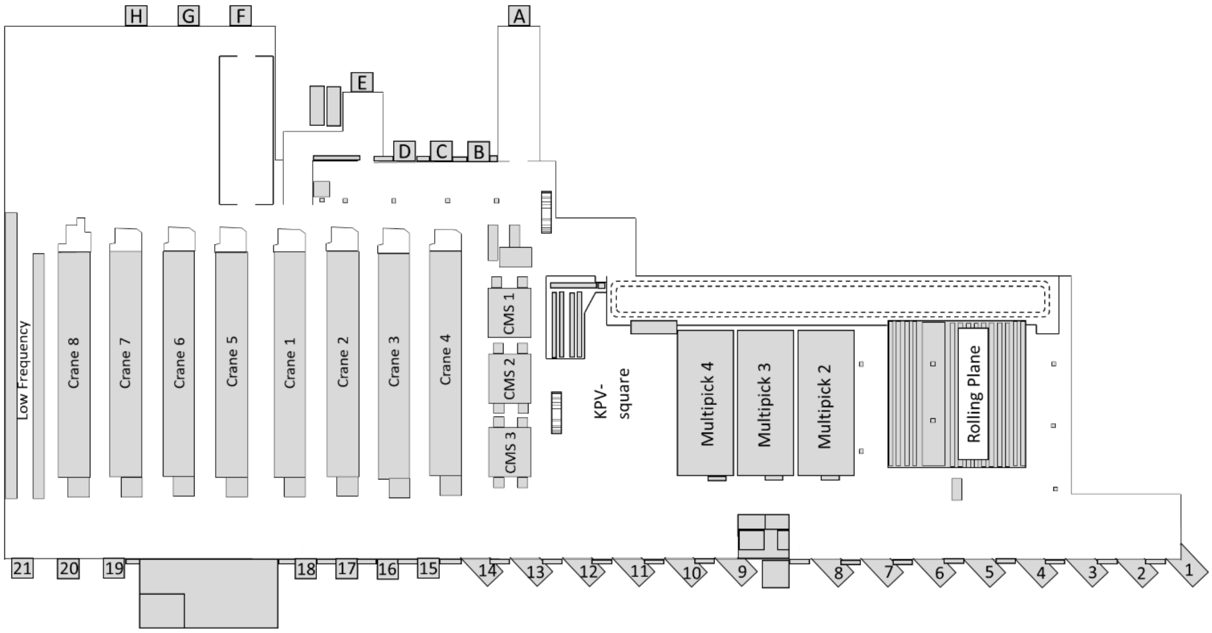


Figure 19. Case company warehouse layout

Crates and tets have their own unique functionalities with products flowing through their system until a counterbalanced forklift must pick them up and places them at the dispatch area. The fine picking zone works differently, however. Here picking of customer unique orders are made by low lift picking trucks moving through the *Commissioner (CMS)* and automated cranes (AS/RS) stacked in parallel, traveling through them in a sort of serpentine pick path. This pathing allows pickers to access every pallet location, though occasionally at the cost of congestion. Once an order is fully picked the pickers travel to the dispatch area or travels back and drops it off at the so-called *KPV-square*, where a counterbalanced truck later moves it for them. Upcoming sections will go in deeper into each of the three material flow channels. While there is no *u-flow* configuration used, there is still a sort of reserve and fast-picking division in the storing of goods. Though the reserve area is stored vertically above the pallet locations in the AS/RS system. There are also some additional buffer locations in the northern part of the warehouse, where goods are stored using floor storage and serves all three of the main flow channels with additional reserve storage capacity.

4.1.2 Handling and storage equipment

According to the interviews and observations, the case company warehouse uses multiple storage and handling equipment. For the crates flow channel, the plastic crates are stored within the Multipick proximity using floor storage, where they are stacked up to six crates high. The tets channel uses floor storage and gravity flow racks to store the SKUs. Its current configuration keeps the put-away and retrieval from interfering with one another. The fine picking flow channel has an AS/RS crane system, which stores pallets at the picking locations on double-deep racks, where the crane executes replenishments upon command from the pickers. Above the picking locations there are pallets stored double- or multiple-deep, three stores upwards on static shelves (exception cranes 6 and 7 which stores in two levels upwards). For the so-called *low frequency (LF)* picking area, that has manual put-away and retrieval, pallets are stored on static single deep shelfs for easy accessibility. Outside of the three main material flow channels, on any intermediate buffer locations and at the inbound area, pallets are stored on the floor stacked up to max two on top of one another.

Besides the automated parts and the AS/RS, many different types of handling equipment, or trucks rather, are used at the case company warehouse. For the fine picking material flow channel, the pickers all drive on low lifting picking trucks that carry four rolling cages or *KPVs*. There is a total of 54 of those trucks, with 48 active ones and the rest acts as spare parts trucks. To these, there are also the picking trucks that are used for picking full pallet loads *EUP* (a flow told to be excluded from the scope of this study by the case company supervisor), of which there are six. There are also eleven counterbalanced forklifts used in the warehouse, mainly meant for the manual aspects of the put-away operations and for transporting tets, crates, and sometimes the KPVs to the dispatch docks. Out of these eleven, seven have a fork mounted to handle pallets, and on the other four, there is mounted on a clamping unit which deals with the low wielding cargo i.e., the tets and KPVs. Besides these main trucks, there are also some miscellaneous ones, such as two reach trucks for the manual storage operations at the LF area, and at the dispatch area, there are low lift trucks and a stacker. Excluding the trucks used at dispatch and three of the ones used in the cold storage warehouse, they all run on chargeable lithium-ion batteries.

4.1.3 Automation

Automation solutions are, according to the interviewees, a prominent feature at the case company warehouse and makes up an integral part of the flowthrough of goods from inbound to outbound. The AS/RS system and CMS for the fine picking material flow channel is one of the key automation solutions utilized. For especially the AS/RS, the case company warehouse was an early adopter in their industry, implementing it in the early 2000s, the CMS implemented a decade later. The eight automated cranes have since their implementation become a staple in the warehouse. They manage the storage functionality of the fine picking flow, relying only on manual input onto the receiving conveyor for put-away and for confirming when to replenish a pallet. The eight cranes work independently from one another, though all are connected to the WMS that monitors inventory levels and accumulates the stock. Pallets are kept double deep at the picking locations for quick replenishments whenever one is emptied. Each crane is double-sided and has on its west side 25 and east side 26 pallet locations, most of which are constantly holding an SKU. The CMS has similar functionalities as the AS/RS cranes, differences lie in that it instead stores SKUs in individual cartons rather than in pallets, that its output is directly linked to the order-lists with 1-9 cartons stacked on a gravity flow shelf often containing a mixture of products and SKUs depending on customer-specific orders, and that it runs on an independent information system. There is a multitude of unique items stored in the CMS, mainly cartons of six with different product characteristics, that are being consolidated by robots to be picked for customer order. The advantage of the system is that it allows for more dense picking, thus reducing the amount of traveling to different pallet locations for items.

Besides for fine picking, automation is also prominent for the crates and tets flows. For both flow channels put-away there is a circulating large-scale carousel system that runs on its own information system connected to the WMS. This carousel carries tets, plastic crates, and after recent modification full pallets if needed. It then drops these off at their respective flow channel. The load carriers are loaded onto to the carousel either manually by the KPV-square (usually goods received at the inbound section from another Arla subsidiary to move through the Jönköping branch’s distribution network), or from the conveyors coming through gates in the wall via conveyors connected to the production facility. These conveyors from production are another automated solution that is used in the warehouse, and just as for the carousel, it is run by an independent information system. After the goods have been dropped off at their respective flow, the crates system is fully automated from there onwards, up until the transportation to dispatch. The crates are a sort of automated overhead crane system divided into three sections, so-called *Multipick* 2, 3, and 4. This system automatically puts-away and stores plastic crates on floor storage, six crates high. These hold staples of stock until orders arrive and then proceed to pick demanded SKUs and places them on a conveyor moving them towards the Multipickers dispatch zones.

To these mentioned main automation solutions, there are also some additional ones used in the warehouse. For instance, barcode-scanning is used to track and trace SKU movement throughout the warehouse in most process steps. There is a further interest to implement more solutions to become an even more mechanized warehouse. There are some solutions currently in the works, being analyzed and evaluated for feasibility. Automation is a key aspect for the case company warehouse and is highly valued.

4.1.4 Information systems

The case company warehouse uses two information systems primarily, an ERP system and a WMS, but also some smaller systems e.g., a system that communicates with the WMS that manages the transportation between the production facility and the warehouse, and an independent separate system that is used for the CMS cranes that reports back to the WMS. For ERP system they use SAP, and it mainly deals with order management for the warehouse, but also some additional functionalities such as salaries. The case company uses central planning for the orchestration of the production and distribution. However, since there are local deviations, each subsidiary has its own autonomous planning unit to make up e.g., any inaccurately forecasted demand figures.

As the central planning sends out information and directions through the ERP, it is then diverted into the compatible WMS used on-site, SwissLog WM. The SwissLog WM system manages the flow of information circumventing the warehouse. This system has been used for some time at the case company and it is not widely used otherwise in the organization. The investigated case company warehouse was at the forefront in the organization in terms of technology and automatic solutions, and thus implemented a system before a standard one was determined in the organization. Today the other subsidiaries use Astro as their WMS, which now inflicts some negative consequences to the case company warehouse whenever widescale changes are made. Nevertheless, this information system is accountable for comprising and generating the order lists, which it does through using the data provided from the ERP and in communication with all smaller more niched systems. This system is linked to all trucks, manages the AS/RS cranes for the fine picking flow channel, and the crates flow’s fully automated overhead crane system.

4.1.5 Labor management

With the extent to which automation is applied for the put-away and storage operations, most labor or person-hours in the warehouse is linked to the picking operations, especially the fine picking. The warehouse typically holds about 60-65 *full-time employees (FTEs)* on average during a day, peaking at about 75 during the most productive days and hours, and reaches its lowest level during the morning of Saturday with only four FTEs. The warehouse uses multiple shifts during the day, morning and afternoon run five to sometimes six times a week, and night shift running all days of the week. To these, there is also a *mid-day* shift, which starts at 11:00 and operates in-between the morning and afternoon shifts.

According to the interviews, the reason for the existence of the mid-day shift has to do with compensation for the current planning structure used at the case company. As mentioned in the previous subsection, the organization has a central planning unit that manages the overall planning procedures for the subsidiaries, and regional planning units that manage local deviations. This central unit possesses the customer order information and does not continuously share it with the regional units. Instead, they compile the information to later share or release it twice a day, in so-called *orderwaves*. They share the customer order information once at 10:30 and then again at 17:00. The earlier 10:30 orderwave is typically the larger of the two i.e., it contains more customer orders. This results in that more picks must be made during expensive hours i.e., in the evenings, since the orders pile up leading to an excess amount during the later hours of the day. This structure of releasing orders to the regional unit twice a day is derived from back in the day when orders were released irregularly, and the sites wanted to have more structure to better plan the workflow. The consequence of which today has led to the additional in-between shift being required to make up for the sometimes-high stream of orders coming in right at the order release.

Then there are also the weekend employees, which is an additional shift group that works every other Sunday. This group makes up a sort of internal pool of extra laborers, that can come in and work extra when needed during the weeks. This group is made up of about 130-150 employees to be potentially available during demand spikes, which typically incurs on the Thursday for retail to cover weekend demand and on the Sunday to cover the subsequent week's demand. Besides the internal pool, the case company also works with three agency firms, which currently account for about 3 % of the total person-hours at the warehouse. The warehouse typically sees demand peaks during the major holidays. It is operating 365 days a year, though capacity is reduced drastically during some special occasions. The only time it is truly closed is between 15:00 to 21:30 on Saturdays.

4.2 Mapping the current state of the warehouse

The Lean philosophy is present at both the investigated subsidiary and the entire organization. Being efficient is an ongoing prominent goal throughout the organization from raw materials to finished dairy products. Desired is for Lean to permeate the organization at all levels. Working with Lean is a strategic choice for the organization to become overall efficient. It is practiced at all locations in the different countries that the company operates in and is applied at all levels of the organization. The case company warehouse is no different. There they work to continuously improve and adapt to their business climate and stakeholder demands. Improvement projects are always running to achieve their desired goals and become "best in class". Lean practices are used as an approach to achieve a high-performing standard of operating procedures. It was introduced at the investigated case company some years ago to help improve the efficiency of the processes. However, despite its importance, it has in recent times been put aside, partly due to Covid-19. The organization intends to revitalize it, as the Supply Chain Management unit is working on new Lean initiatives to implement organization wide.

While they wish to use even more, there are currently several tools being used, for instance, Lean visual management boards are used for frequent follow-ups, Kaizen for continuous improvements, and 5S to improve work standards and obtain an organized workflow. The follow-ups are held before management and operators, to ensure personnel on each hierarchical level is in the know about what is transpiring and gets an opportunity to share their insights. They have also, from a recent project they were involved in, started to work in Sprints and with Agile. As mentioned, they work on a lot of different projects at the case company warehouse, often with goals of improving efficiency, make cost savings, and improve transparency. All common themes and closely associated with Lean, which is important to the case company to adhere to the organization's competitive strategy. They strive to become Lean and JIT in their operations and process flow. The following subsections take a deeper look into the material flow and main flow channels at the case company warehouse.

4.2.1 The material flow

Based on made interviews and observations, the current layout of the investigated warehouse has the inbound located in its northern end and the outbound in the southern region. Once goods arrive at the warehouse, if it is not from the in-house production facility, it undergoes a brief visual inspection, mainly ensuring the packaging is acceptable and is then scanned to register its arrival to the WMS. Depending on the SKU it arrives in, and what product it is, it goes into one of the three primary flow channels at the warehouse, fine picking, tets, or crates, as the Spaghetti diagram illustrated in Figure 20 shows. There is also a fourth flow channel that is intertwined with fine picking, called *EUP (European Pallet)*. In the EUP flow, pickers drive through the AS/RS cranes, picking and stacking SKUs on European Pallets. This flow channel is however excluded from the scope of the thesis study, because of the case company's request and its insignificance to the total (it merely makes out about 1-2 % of the total volume of the fine picking flow channel). Some data entries from the case company WMS have unfortunately merged the data from the EUP with fine picking, making it an inevitable part of some of the gathered data, instances of which are stated in the upcoming subsections.

Each of the three main flow channels contains its own version of put-away, storing, and picking, and will be described in more detail in the following subsections. When customer orders are placed the WMS processes these, reviews the current balance and status of the warehouse and generates order-lists for picking. Once goods have been picked based on generated order-lists to the three flow channels, the goods are moved to the outbound area. Where they are designated to one of the 21 bays, based on the customer order. Each of the bays could contain any combination and mixture of products and SKUs from the three main flow channels, and additional ones, all dependent on the customer order characteristics.

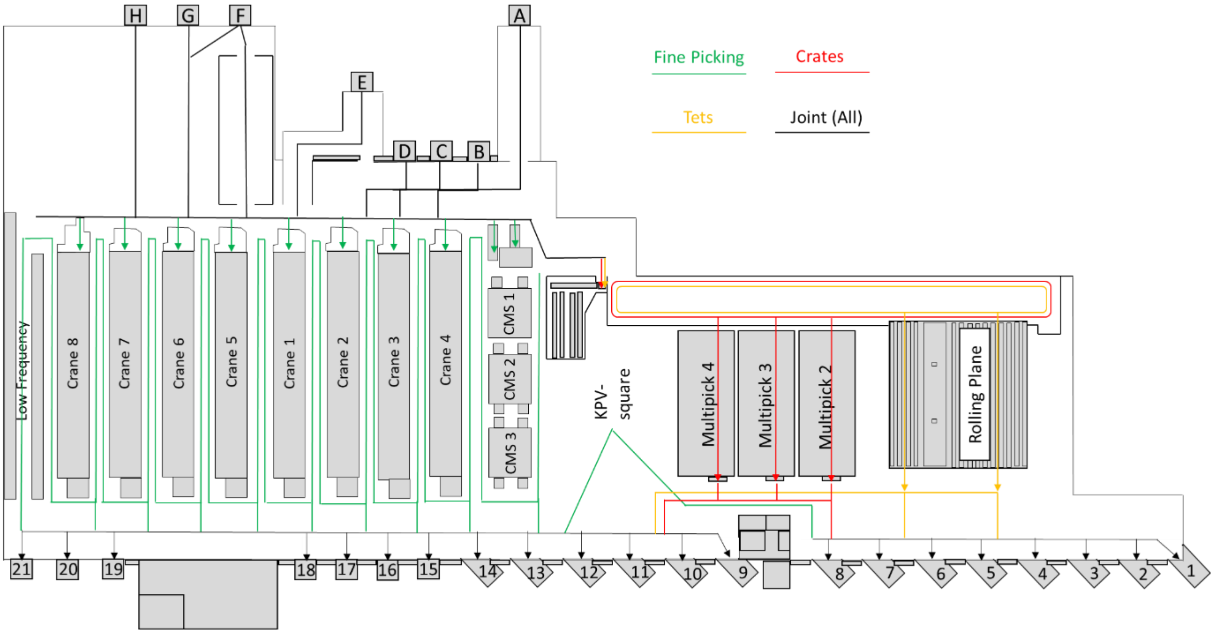


Figure 20. Spaghetti diagram visualizing the flow movement in the three main material flow channels

On-time delivery to bay is one of the most important KPIs for the warehouse and is carefully monitored at all times. With a current goal of 83 % on-time delivery to bay, which is taking into account about 45 min of slack, meaning that while they may not always achieve the desired target at the warehouse, the goods are still rarely late to the end consumer. Nevertheless, when all (or most) of the goods have been picked and deposited at the right dispatch bay, they are loaded onto the truck by the truck drivers, who from that point on have the responsibility of handling the cargo. The goods are loaded manually by the drivers, if needed the warehouse has loading support, where staff from the cold storage warehouse can assist the loading process. However, the truckdrivers, who sometimes are Arla distributors and sometimes outside haulers, have the main responsibility. Upon loading the goods are scanned to check that the amount is correct and to register its ready departure. Scanning is done throughout the warehouse from inbound, within each of the flow channels, and up to the dispatch to monitor the warehouse activity. Brief quality control of the load carriers is done at dispatch to ensure the right products are picked and that there are no damaged goods. Once loaded, the goods are shipped out and officially out of the warehouse's hands. The data and information regarding each material flow channel in the following subsections are all derived from the qualitative gathered data, most of it from the interviews.

4.2.2 Fine picking

The fine picking flow stores a vast variety of SKUs on pallets to be picked as either full carton or broken case. Excluding the intertwined EUP flow, this flow channel constitutes a large percentage of the total number of orders and is currently seeing a trend of increased demand, which could be related to the influence of Covid-19. This flow has, just as the other flows, a mixture of both automated and manual processes. Pallets arrive via the inbound bays, once entered these are checked and scanned, after which they are moved to the receiving sections at the AS/RS storage system, or to the CMS cranes by counterbalanced forklifts. Once approved by the AS/RS scanning, the pallets are stored away 2-3 pallets high in a sort of *reserve* area until *replenishment* is needed at the picking location. Picks are being made from pallets. Once a pallet is empty and needs replenishing the picker logs it on the low lift picking truck interface, that is connected to the WMS, which instructs the AS/RS to replenish the picking location. The CMS works similarly to the AS/RS, the difference being that it is an independent system and that it stores cartons instead of full pallets. In the put-away it is thus loaded carton-wise and then stored away 14 carton levels high with each level containing 6-7 cartons. Another important distinction here is that this system loads the pick-faces with the cartons required for a specific order, meaning that the CMS loads a pick-face with the cartons that the order-list needs, stored nine cartons deep per picking location.

From made observations, following the picker's point of view, the order picking starts with the picker printing out an order receipt, which scanned initiates the route. Each picker drives a low lift picking truck that is driven by rechargeable lithium batteries and can carry up to four rolling cages or as they call it KPVs. Pickers are directed to picking locations by the monitor mounted on the truck that is connected to the WMS. These directions, besides location, also specify the quantity to be picked and in which of the four KPVs it should go into. All trucks follow the same pathing, moving one crane-row at a time. Starting off at the CMS and then moves through all eight AS/RS cranes, which are each double-sided i.e., 16 rows to pass through. If all items are not already picked, the picker reaches the end of the route at the LF area, which contains slow-moving SKUs not stored in the automated cranes. The LF area is fully manual, where put-away, receiving, and replenishments are all performed manually in single-deep shelves by a reach truck. Once the picker has picked all items listed by the monitor, instructions on which bay to drop them off at reiterates (visible on the receipt). When dropped off at the dispatch area the picker scans the order receipt signaling that the order has been picked and is ready for loading. An exception to this drop-off routine is if the orders are headed to bays 1-8, for which they are instead dropped off at the starting area, at the KPV-square, and then later transported to their respective bays by a counterbalanced forklift. The reason for this routine has to do with safety and congestion. At bays 1-8 it is less aisle space and more traffic of people walking around by the tets flow channel.

The upper figure in Figure 21 shows a description of the flow following the VSM templet, and the lower shows a Spaghetti diagram of the flow movement of the current state for the fine picking material flow channel in the warehouse. A FIFO-policy is predominantly used in the system, exceptions can however occur. There are no hardcopies in the immaterial flow, excluding the order list which merely acts as a code to initiate the route-list and as a receipt when finished. There are eight listed steps in the flow within the warehouse, four of which make up the activities unloading, put-away, picking, and loading. The rest are intermediary storage points and the automated storage.

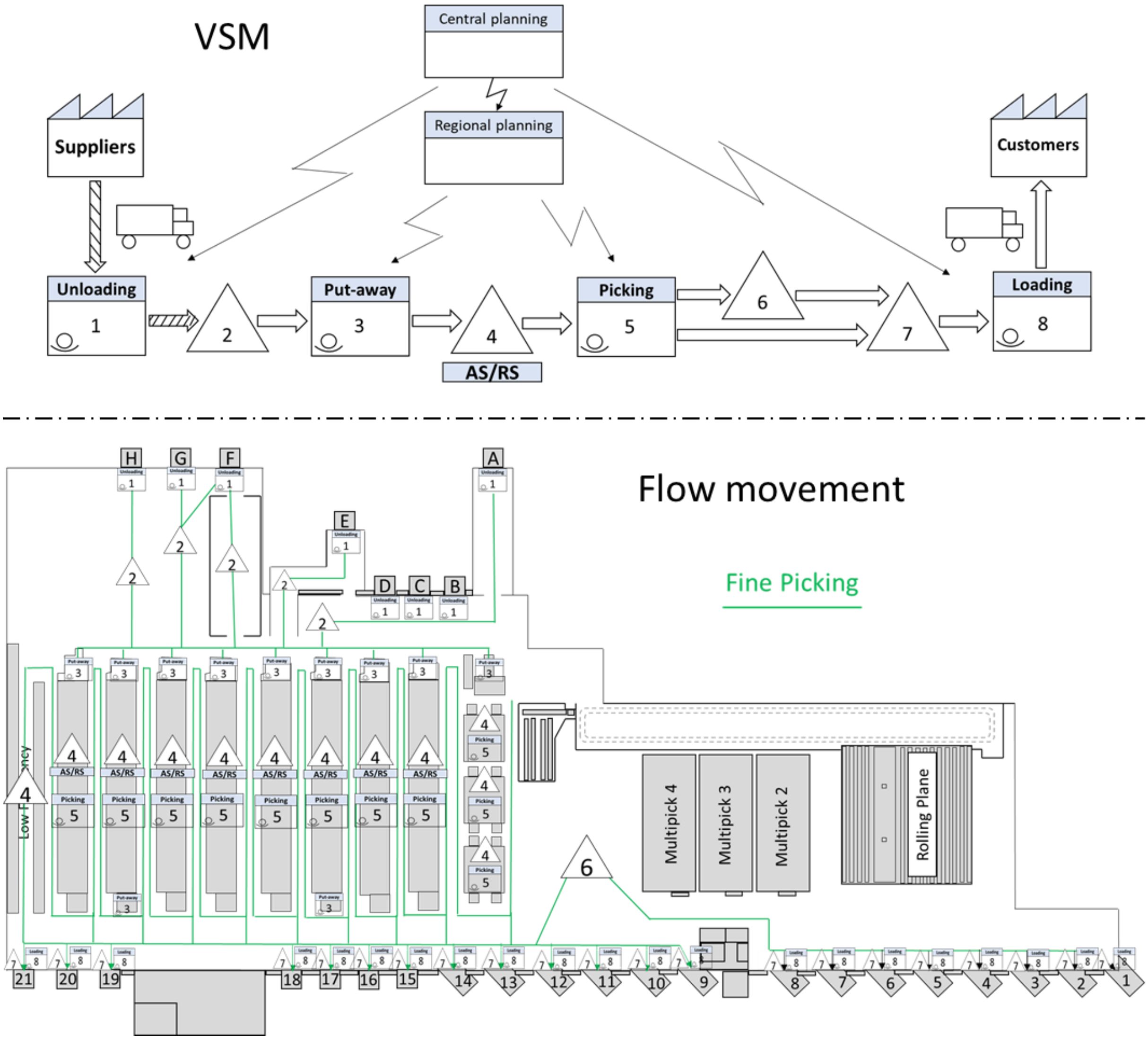


Figure 21. Current state VSM with Spaghetti diagram below – fine picking

4.2.3 Tets

Based on the interviews, tets is the least automated flow channel in the warehouse. Unlike fine picking which has an extensive list of different products and SKUs, here individual cartons e.g., 90 1,5-liters or 120 1-liters, are stored in a 105-centimeter-high rolling cage or tets. In this flow, goods either arrive from the northern inbound area, just as for the fine picking flow or on conveyors going through the wall from the internal production unit. The goods that arrive from the inbound area is checked and scanned before it is moved towards the put-away for the tets flow, whilst the goods coming from the in-house production unit is checked at the previous stage. For put-away the tets are being transported to their main storage on a horizontal carousel. Those from the inbound area are placed manually on a loading plate awaiting the carousel, and those from the in-house production are being picked up by the carousel at the end of their respective conveyor track. Once on the carousel, the items await depletion onto the main storage of tets. The tets are stored on a form of gravity flow racks or on the floor, 36 pallets deep on 48 rows waiting to be picked. Here instead of the vast variety of SKUs in the fine picking area, there is here 46.

Following the picking procedure of this flow, the picker prints out a picking list (physical form) and walks to the row with listed SKU and moves the tets to a waiting area. Once at this waiting area the order receipt is placed onto the picked tets. Counterbalanced trucks then arrive to pick these up, look at the order receipt to indicate in which bay to drop them off, and drives off to that location. Once at the dispatch the tets are dropped-off, after which their readiness is confirmed for loading onto departing truck.

VSM of the current state at the tets material flow channel is illustrated in Figure 22, accompanied below by a Spaghetti diagram visualizing the flow movement in the warehouse. This shows the two paths the tets can take before entering the carousel system. Just as for fine picking, there is a push flow at the inbound section and a FIFO-policy used. There is an electronic immaterial flow for surrounding parts, but for the picking process hardcopies are used. Tets have four processes and a total of ten activities, where the rest constitutes the gravity flow rack storage and intermediary buffers or waiting areas.

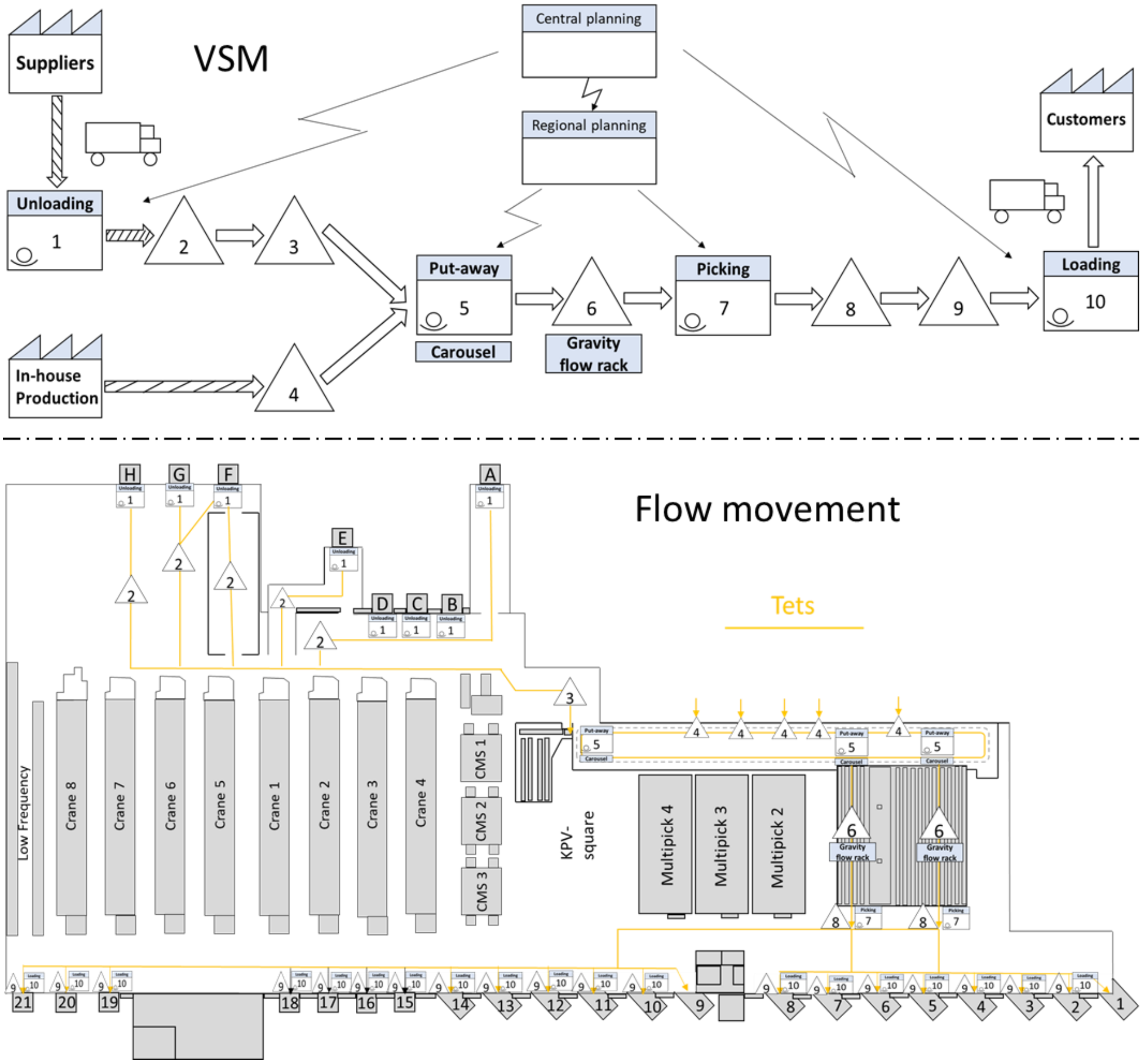


Figure 22. Current state VSM with Spaghetti diagram below – tets

4.2.4 Crates

The last of the three main material flow channels is the crates flow, which has the most implemented automation solutions out of the three. Just as for tets, the put-away for this flow has products either coming from the in-house production unit or from an outside source at the inbound area. For these plastic crates, containing 12 or 15 cartons depending on carton size, only a smaller portion comes from an outside source. The crates are loaded onto the carousel in the same way as the tets but dropped off at a different drop-off site. At the drop-off site, it awaits the automated overhead crane system to pick it up and then place it on a floor storage area that stores plastic crates 1-6 units high. The Multipick system is divided into three areas and is controlled by the WMS. It performs the order-picking autonomously, dropping off picked orders at a drop-off zone, which transports the picked crates to a waiting area where it exits the system and signals its readiness. As the crates are waiting in one of three possible waiting zones, the counterbalanced trucks receive a notation to collect the plastic crates and instructions on which bays to drop them off at. Once at the bay, it is, just as for the other flows, loaded onto the truck by the truckdriver and shipped away to customer.

The VSM for this flow can be seen in Figure 23, along with a visualization of the flow movement in the warehouse. As stated, it shares a lot of activities with the tets flow channel, and thus has a very similar current state map. The difference between the two is that there are no hardcopies at all used for the crates flow and that the automated Multipick system performs the storing and picking of the SKUs.

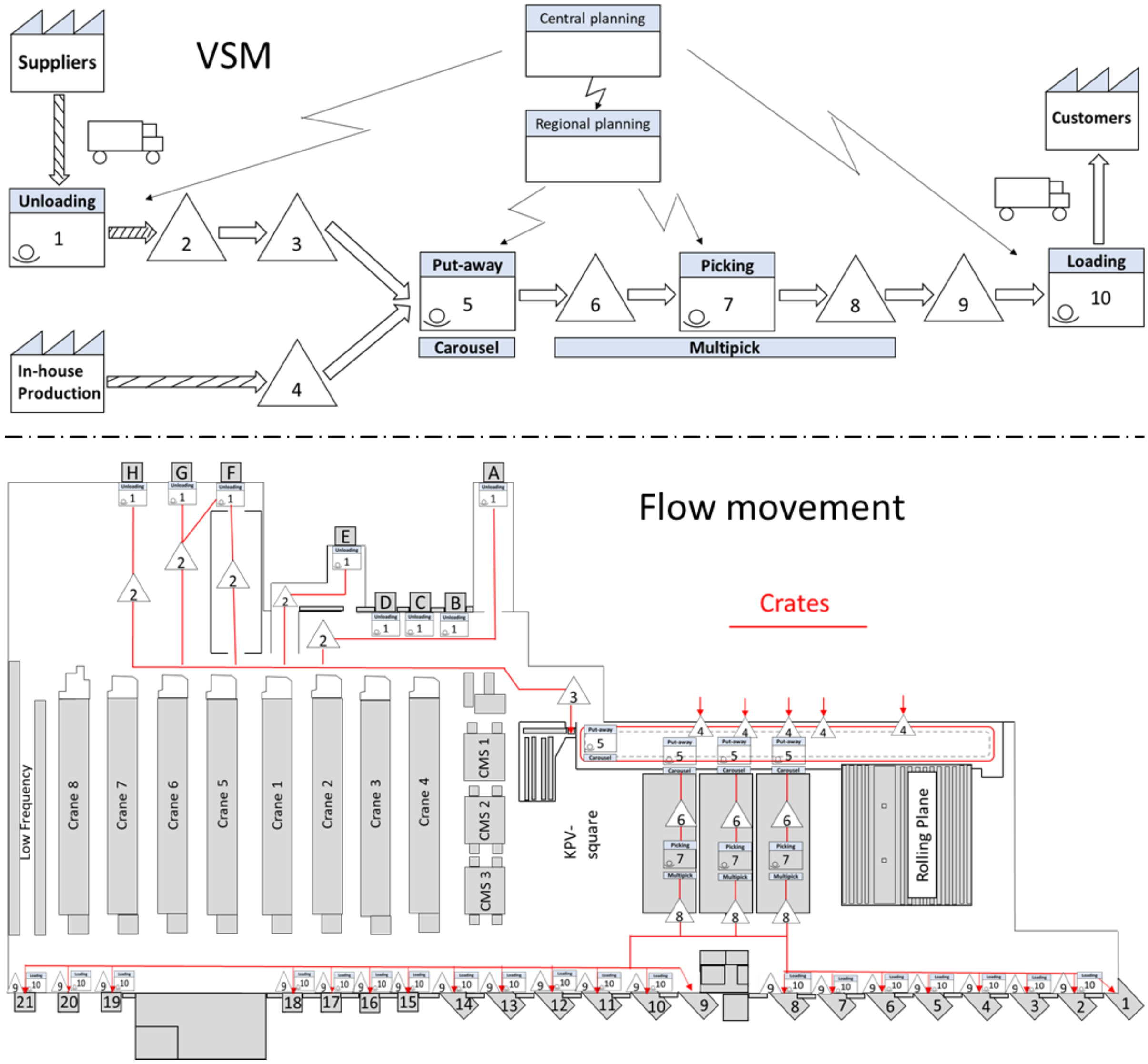


Figure 23. Current state VSM with Spaghetti diagram below – crates

4.3 Activity profiling

To get a holistic overview of the warehouse's activity, some key statistics are compiled in Table 10. This shows a general summary of the warehouse environment in a simplistic way and helps to provide an understanding of the customer orders which drive the system. Table 10 portraits an overview of the physical characteristics of the warehouse, what equipment and storage types are used, SKU characteristics and utilization rates, order characteristics, and workload. With this compiled, a fundamental statistical understanding of the investigated warehouse is gained. Data is compiled for the whole warehouse and for each of the three main material flow channels. For some instances though are metrics not available or applicable and are therefore left as empty cells.

Table 10. Key warehouse metrics

	Warehouse	Fine picking	Tets	Crates
Area m^2 (with Inbound and Outbound)	14510	3150 (6350)	1610 (4810)	1895 (5100)
Height m	4,5-7,7	7,7	4,5	7,7
Material handling equipment	Multipick, Low lift picking trucks, Counterbalanced trucks, Low lift trucks, Stacker trucks and Reach trucks	Low lift picking trucks, Counterbalanced trucks, Low lift trucks, Stacker truck and Reach trucks	Counterbalanced trucks	Multipick Counterbalanced trucks
Storage type	AS/RS, CMS, Static single deep shelfs, Gravity flow racks and Floor storage	AS/RS, CMS, Static single deep shelfs and Gravity flow racks	Gravity flow racks and Floor storage	Floor storage
Broken case, full case, or Pallet picks	Broken case, Full case (Carton) and Pallet picks	Broken case, Full case (Carton) and Pallet picks	Full case (tets)	Full case (plastic crates)
Number of SKUs	561	475	46	40
Average rate of introducing new SKUs	Every 3 month	-	-	-
Picking locations	872	821	48	3
Utilization	87 % (95 %)	86 %	98 %	100 %
Average number of shipments received per day (pallets)	889 (1096)	-	-	-
Average orders shipped per day	1856	1059	451	346
Average order lines shipped per day	13272	11014 (43313)	1353	892
Average lines per order	7,15	10,41 (40,89)	3,03	2,58
Average items per order line	16,27	12,16	128,25	60*
Working days per year	365	365	365	365

*Approximated value

Reviewing the data, fine picking has nearly twice the area of the other two, not including the inbound and outbound sections as these are shared and have an area of about 3200 m^2. There is a multitude of equipment and storage types used in the warehouse for the different flows. Various picking types are being made for fine picking but only full case picking for tets and crates. Most SKUs are allocated in the fine picking flow which in turn also has the most picking locations. The utilization rate is in general high. Fine picking has significantly more orders shipped per day and more lines per order on average (especially during just the weekdays as the parenthesis value portraits), and they work all year round. The following subsections dwell deeper into the significant areas for the case company based on the conducted interviews and the comprised data in Table 10. Data for each subsection is based on gathered quantitative data, predominantly from the WMS.

4.3.1 SKU popularity distribution

With over 500 SKUs in the warehouse, there are certain differences in terms of picking popularity i.e., how frequently customers request an SKU. Since there are different SKUs in the three material flow channels, separate graphs had to be produced for each. Data is gathered from the case company warehouse's WMS system, using a normal week i.e., no special holidays or contextual factors influencing more than typically expected, in October 2020. Using a daily average, taking all weekdays into account, for the fine picking material flow channel about 20 percent of the 454 SKUs account for half the requested number of picks, as seen in Figure 24. The picking popularity distribution most resembles an exponential distribution, making an ABC-classification applicable, though perhaps not as steep a distribution as an ideal exemplification would be. The three most popular SKUs in the flow is 6-carton 1-liter packaged strawberry/wild strawberry yogurt, 6-carton 1-liter packaged wild berries yogurt, and 6-pack 250 grams plain cottage cheese (4 % fat). While cheese in general is not distributed by the Jönköping warehouse, cottage cheese is. Based on the interviews the picking popularity distribution remains relatively consistent all year round, though with some exceptions and seasonal differences e.g., the spike of sour cream sales during the midsummer week. This distribution showed in Figure 24 does not include the EUP flow.

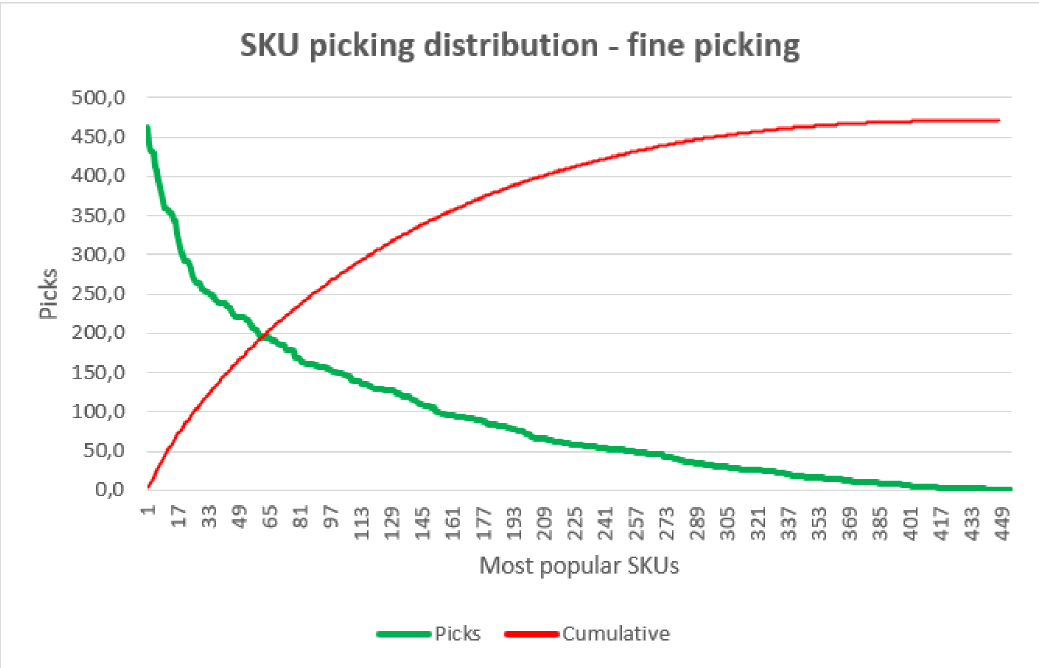


Figure 24. Picking popularity distribution – fine picking

Using the same data of a week in mid-October to produce daily average figures, a heat map is constructed to provide a bird's eye view of the warehouse's SKU popularities, in Figure 25. The heat map illustrates the frequency of requests for the different SKUs using a color spectrum ranging from lowest frequency of requests at zero shown as white and highest frequency of requests at 462 during a day as bright red. The SKUs with the highest popularity are allocated around the center of the eight AS/RS cranes, with some exceptions, and unsurprisingly the LF (furthest to the left) area SKUs have the lowest frequency of requests. Featured SKU allocations in Figure 25 are however based on a snapshot of the warehouse configuration in May 2021, meaning that there are some deviations between the data points. Amongst the AS/RS there have, according to the interviewees, not been any drastic changes and should align decently. For the CMS and LF area however, there are more significant deviations. The CMS (furthest to the right) has more than double the picking location capacity that is featured in the snapshot and illustrated in Figure 25, which entails that there could be vast differences between the two data point entries. The LF area has the biggest turnover of SKUs in the warehouse, and in 6-7 months there have been SKUs that have been removed for some new ones to take the places. This entails that the heat map does not portrait a completely accurate image of the activity in the warehouse. However, based on the interviews, the overview is similar all year round. There are some inaccuracies, but the heat map in Figure 25 should produce a fair approximation of what the SKU popularities typically look like. The green arrows show the movement of the pickers in the flow channel.

Figure 25. SKU popularity heat map - fine picking

Using the same approach again for the tets material flow channel of taking the same sample week of October 2020, the picking popularity distribution follows an exponential distribution, as shown in Figure 26. For this flow, the distribution is steeper and has a longer tail, making it more apt for an ABC-classification. Out of the 42 counted SKUs, the five most popular items account for 50 % of the requested number of picks. The most popular SKU (by far) for the tets flow is the 1,5-liter regular milk (1,5 % fat), followed by 1,5-liter standard milk (3 % fat) and 1-liter regular milk (1,5 % fat). This flow channel has consistent distribution all year round (can be small differences), according to the interviewees. For the crates material flow channel, specific SKU picking data is lacking, and therefore no distribution graph can be made for the 40 featured SKUs in the flow. Based on the interviews though it seemingly follows the same pattern as the tets flow channel, with similar items flowing through it but stored differently. No heat maps are constructed for the tets and crates flows, due to data shortage. For crates it is arguably not even be feasible, since there are not really any picking locations in the classical sense, however for tets it would have been fruitful to illustrate picking popularity along the 48 rows.

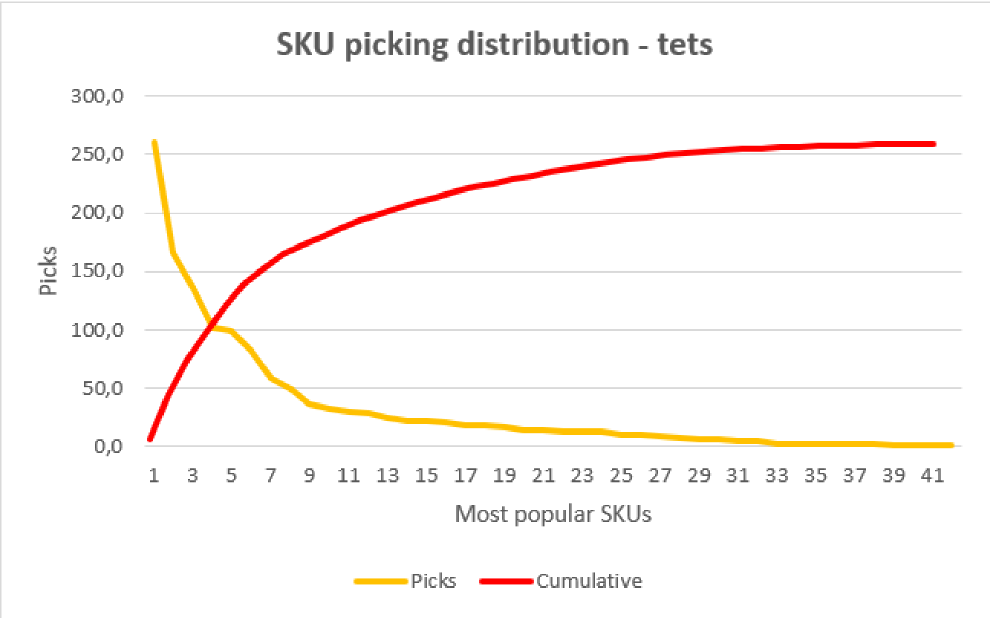


Figure 26. Picking popularity distribution – tets

4.3.2 Order characteristics

There are a lot of orders streaming in and out of the case company warehouse. The inbound flow is relatively constant and follows a push policy i.e., it is sent to the case company warehouse based on forecasts made by the central planning unit. Shipments are received daily at the warehouse, in accordance with the planning department's forecasts. The total amount coming in per week varies with trends and seasonality. With pallet shipments received every week of the year, it arrives on average about 6220 per week and 889 per day. This data is derived from the case company warehouse's WMS, using the calendar year 2020 for data points. A sample week is used to normalize the variation between the weekdays, displayed in Figure 27. The figures show that the received pallets fluctuate between approximately 900-1100, except for Saturday which only accounts for a small fraction of the total amount received. Peak day is Thursday, closely accompanied by Sunday and Friday.

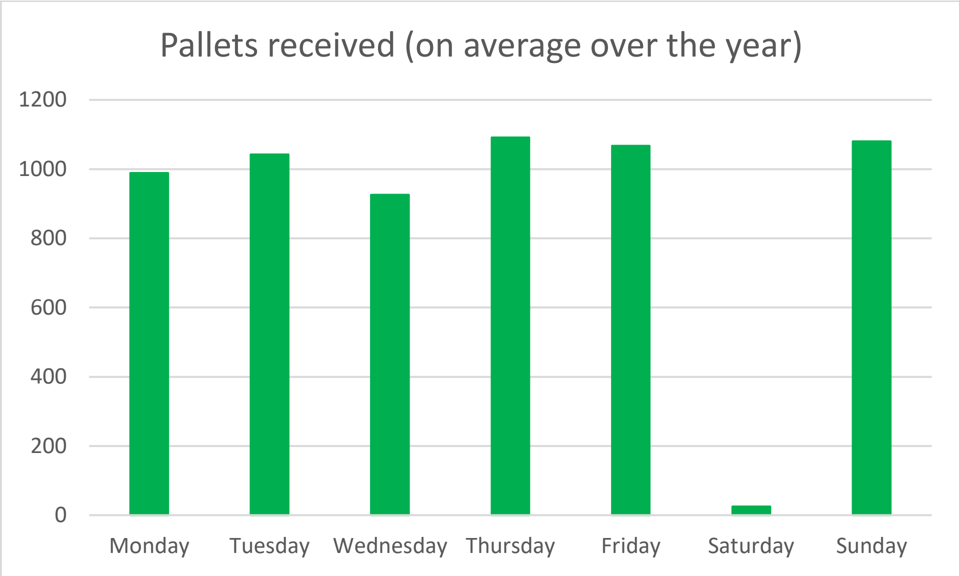


Figure 27. Average received shipments daily

Shifting the focus to the orders shipped out, Figure 28 shows the number of orders shipped each weekday for an average week containing no special holiday in October 2020. This figure shows the total amount shipped for all three flows, and the EUP flow since the gathered statistics for fine picking has the two merged in this instance and could therefore not be excluded. However, the EUP flow only has a minuscule impact on the total for fine picking in terms of the number of orders shipped, approximately 1-2 % of the total amount of orders attested by the fine picking flow. It indicates that there is a relatively consistent flow of shipments out Monday till Wednesday, then with two peaks on Thursday and Sunday, a slight decrease on the Friday, and a substantial decrease on the Saturday. The two peak days can be explained by the ordering structure, where particularly the retail clientele place more orders during the Thursday to fill the need for the weekend and on the Sunday to fill the demand for the subsequent week. The decrease on Friday is caused by a smaller second orderwave, and the significant decrease on the Saturday is caused by the warehouse closing the operations for a major portion of the day.

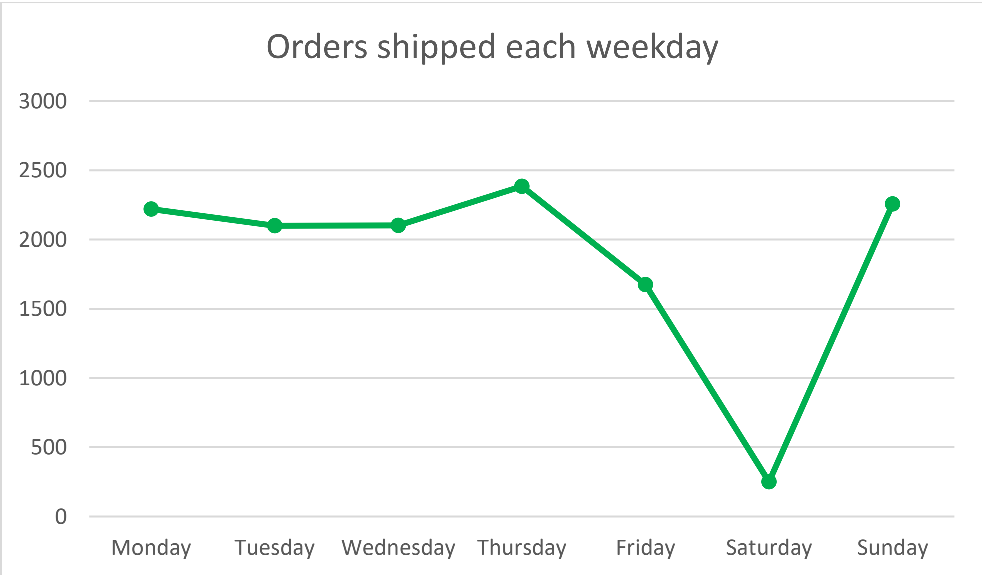


Figure 28. Average number of orders shipped daily

Looking into the daily shipments out, extruded from the same data as Figure 28, Figure 29 shows an hourly average for Mondays-Fridays. Weekends are excluded here because of the complete shutdown during the Saturday, and Sundays only having a handful of orders in the morning, for the average distribution of the hours of the weekends see Appendix B. The averages show that there is significant variation between the high and low points of shipped orders, something explained by the current order structure and workflow. There are two peaks, one at 13:00 and the other one at 20:00, both are a resulting culmination of when orders are released to the warehouse, at 10:30 and 17:00. There are significant low points as well, e.g., at 11-12:00, 16:00, and at 22:00 which essentially are a result of the breaks during the shifts. Night keeps a relatively stable level of shipped orders up until the morning shift starts where all the final orders released from the 17:00 orderwave are picked.

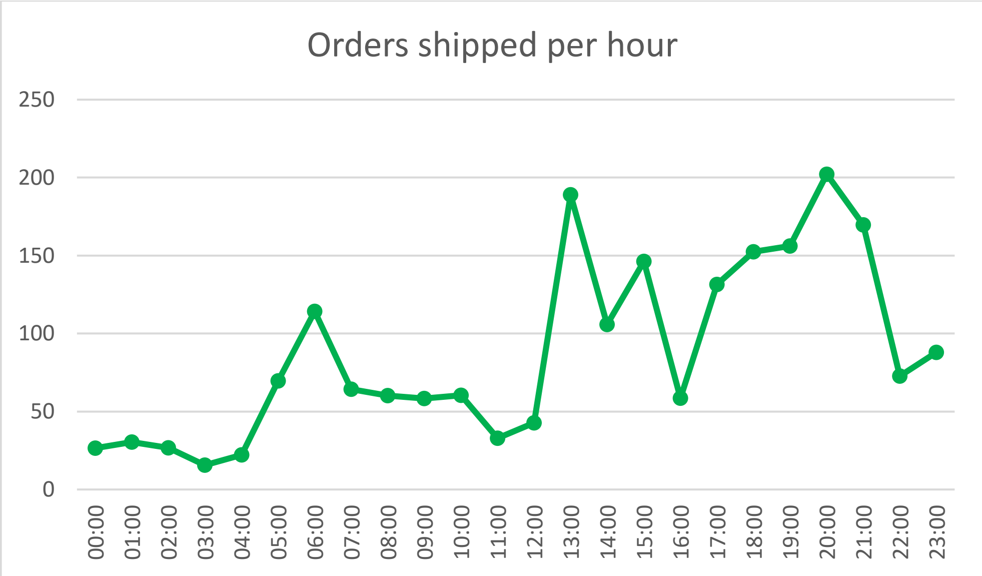


Figure 29. Average number of orders shipped hourly

The distribution of sent out orders between the three main flow channels is visualized to the left in Figure 30. This image shows that on average the fine picking (including EUP) accounts for nearly 60 % of the entire number of orders shipped out and that tets and crates account for about 20 % respectively. This distribution is however not fully indicative of the throughput, as it only accounts for the number of orders and not the volume or weight. The typical order from crates or tets is significantly larger than those from fine picking. A denotation must be made regarding crates however, as the data collected from that system is not measuring the same time period, but rather the same dates two years prior, so there could perhaps be a slightly different outcome if measured from the same year as the other two.

Reviewing the weight distribution of the orders sent to customer for each of the main flow channels, there are similar shares of orders sent out, in the sense that it is a clear majority for the fine picking and split between the other two, as the image to the right in Figure 30 shows. The difference here being that tets account for nearly double the weight of the crates flow, which can be explained by the SKU sizes. Tets are always sent as a full unit, where one can contain 120 l liter packages or 72/90 1,5 liters (depending on the packaging), whilst one crate contains 12 1,5 liters or 15 1-liter cartons (note that one load could equal a stack of up to six crates).

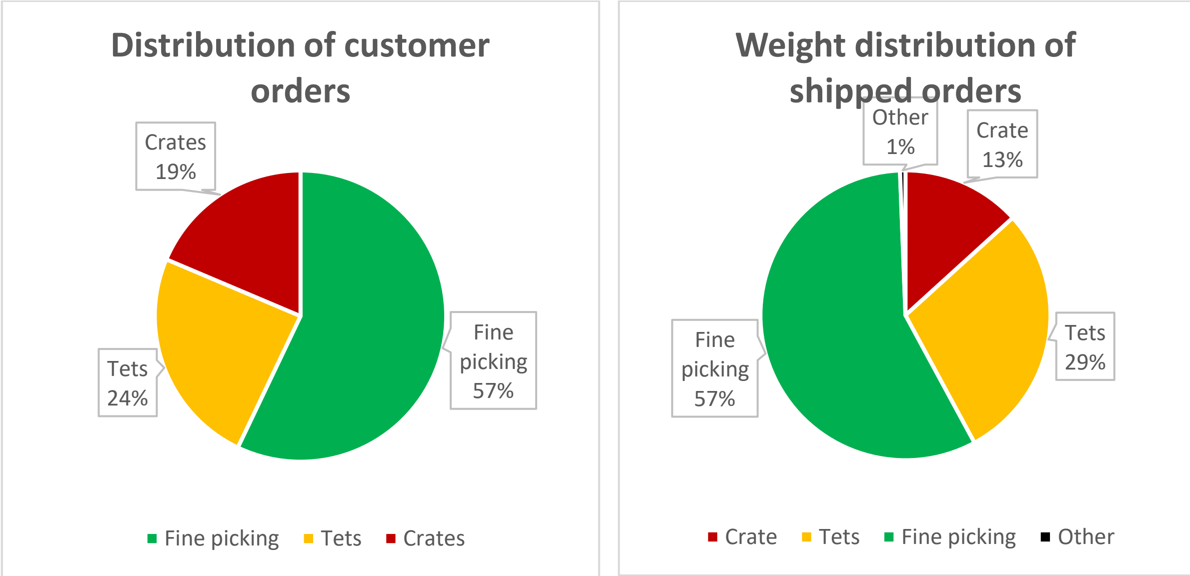


Figure 30. Shipped order distributions

Looking at the orders themselves, with an average of about 41 lines per order for fine picking during the weekdays, and 2-3 during the Sunday, the distribution of lines per order for weekdays can be found in Figure 31 and Sundays in Figure 32. Saturday is excluded because its data act sporadically, though the average has essentially the same distribution as the Sunday just with a fewer total amount of orders. The number of lines per order follows an exponential distribution for both weekdays and weekends, but is significantly steeper for weekends, with a vast number of orders containing 1-3 (especially one) order lines. Weekdays do however have a longer tail than the weekend. The reason for this difference could be caused by complementary orders from the customers being placed during weekends, or just more backorders.

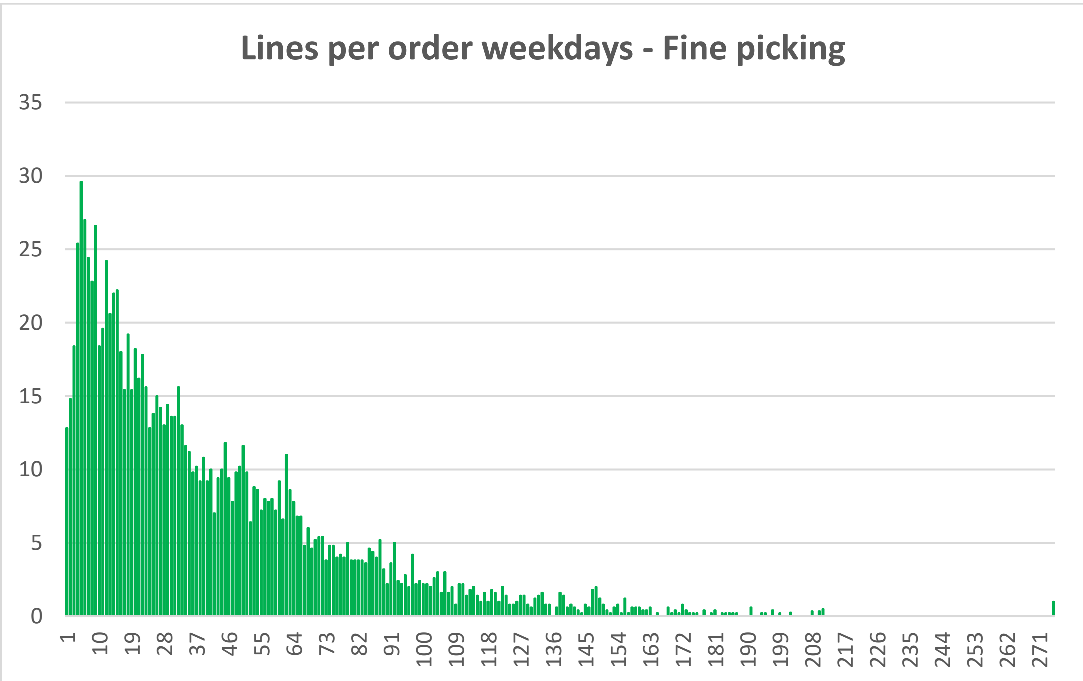


Figure 31. Average lines per order weekdays – fine picking

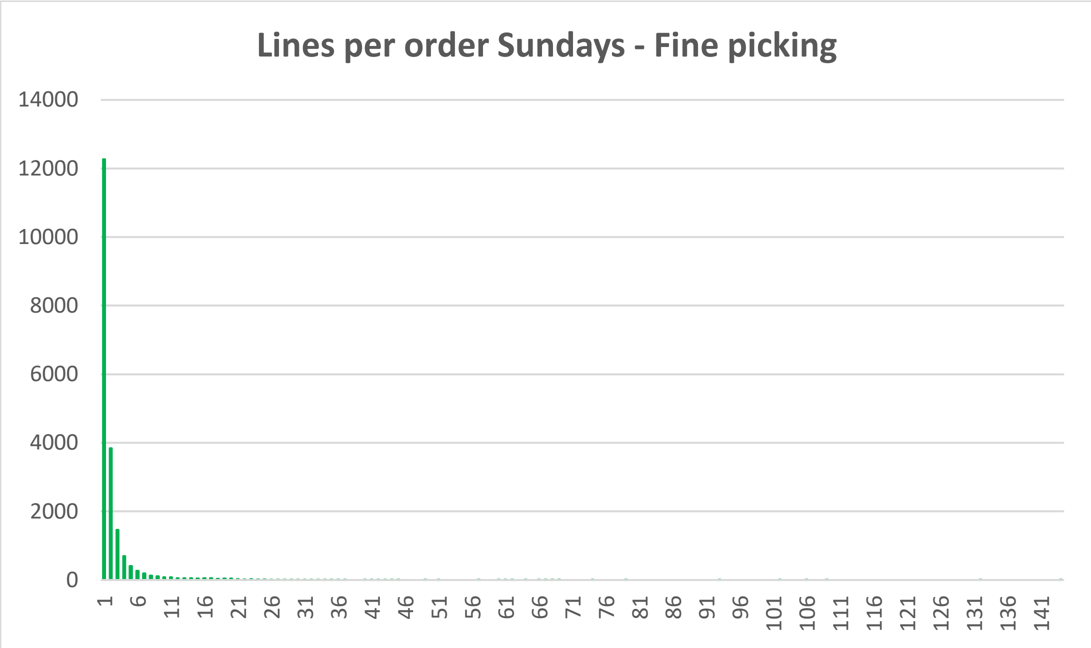
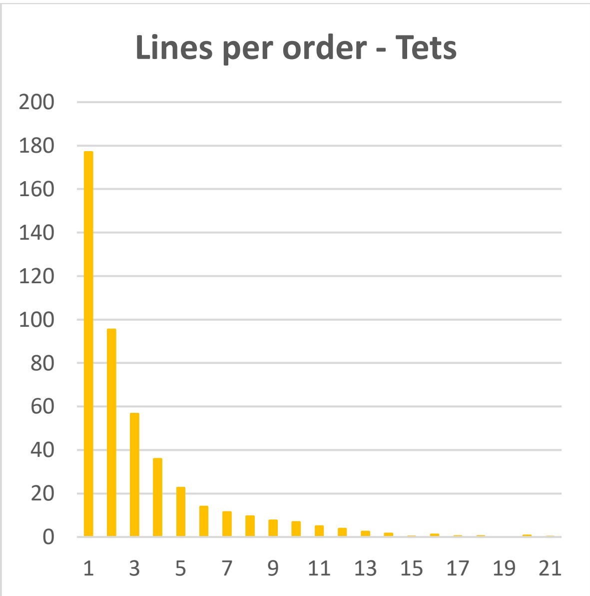


Figure 32. Average lines per order Sundays – fine picking

For tets, there is an average of three lines per order for the entire week, the distribution of which is portraited to the left in Figure 33. Weekdays and weekends are nearly identical in distribution for this flow channel. The last flow channel, crates have data measured differently. Here it is measured as loads per order, where one load entails however many are picked up at the deposit station in any of the three Multipick systems i.e., anything from 1-6 stacks high. For crates, the loads per order have an even shorter tail and average about 2-3 loads per order for any day of the week, except for peak holidays, shown to the right in Figure 33. There is no significant difference in distribution between loads per order during the weekend or weekdays, other than a lesser amount of total picked orders during the Saturday. For the difference between weekdays and weekends for tets and crates, see Appendix C.



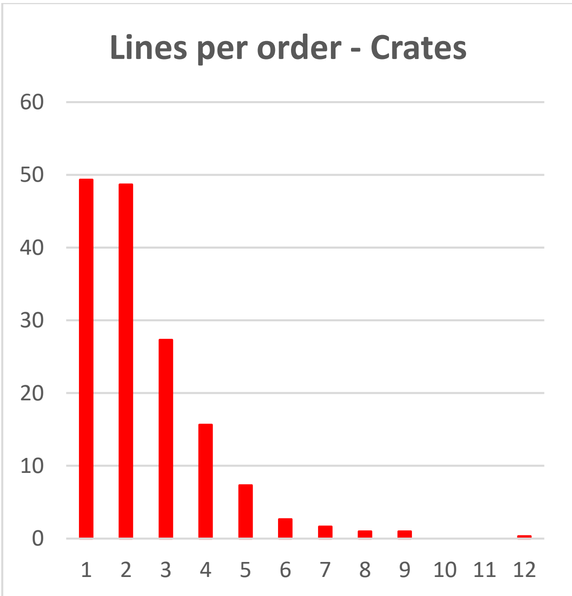


Figure 33. Average lines per order – tets and crates

4.3.3 Bays

Another indicator of the flowthrough and activity in the warehouse is the departure from bay distribution. By compiling average daily shipments from bay for the three flow channels, there are clear distinctions between the number of orders departing from each bay. Figure 34 shows this distribution, in which the daily average ranges from at lowest about 43 at bay 1 to highest 148 at bay 13. The daily average metrics stem from the case company warehouse WMS, where a sample week in October 2020 is used, that contains no special holidays or any significant external factors affecting it. An important disclaimer, however, is that for the crates material flow channel there is data shortage, departures from bays 1-2 are missing, and it does not measure departures but rather the times loads are picked up at the Multipickers' dispatch. This leads to some data inaccuracies; the crates flow is however the flow with the lowest total throughput impact, making the total still relatively uncompromised. Bay 11 probably has the actual lowest figure of daily shipped orders of about 45. Important to note is that, as the previous section showed, the fine picking flow has a large impact on this measure, since it represents about 60 % of the total amount of orders departing from the warehouse. The daily shipment averages for each flow channel can be found in Appendix D.

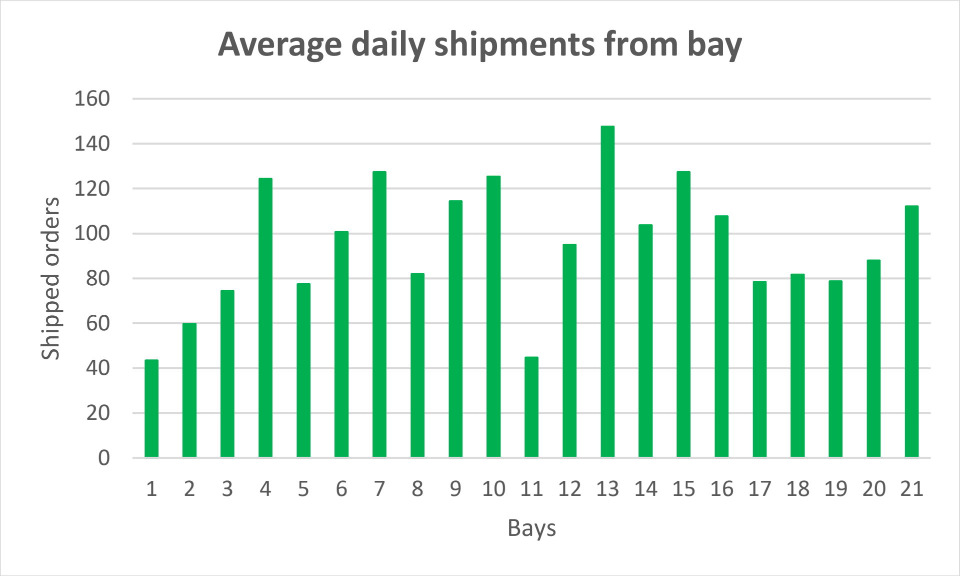


Figure 34. Average number of orders shipped from bay daily

Looking at the *mean time between departures (MTBD)* for the individual material flows using the same data entry as for the total average, crates have the most downtime for bay 12 at about six hours, followed by about five hours for bays 9 and 19. Figure 35 shows that the busiest bays are 3, 10, and 16 with an average MTBD of about 2,5 hours. Again, it is important to note that data is lacking for bays 1 and 2, and exact departure times are missing. For tets and fine picking, the MTBD have similar distributions, with the clear victor of highest average downtime at about eight hours per shipment at bay 11. Tets have the lowest MTBD for bays 10 and 17 with just about two hours downtime between shipments, which Figure 36 illustrates. Identical for fine picking, only that it is just above two hours, as seen in Figure 37. It is significant to note that for almost all cases there are at least two hours of downtime between any departure on average. However, to this it is also notable that for many cases multiple departures occur within rapid succession, by having e.g., three departures within the span of 30 minutes.

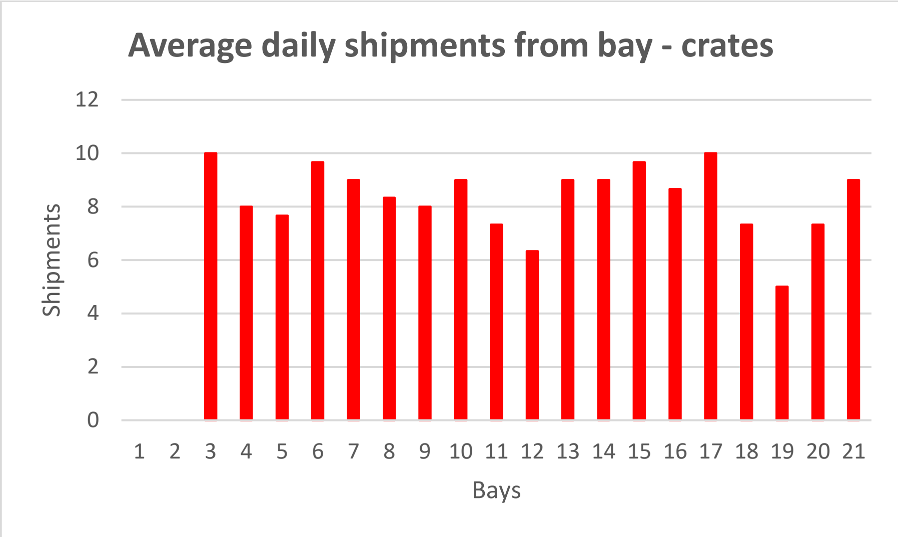


Figure 35. Mean time between departure from bay – crates

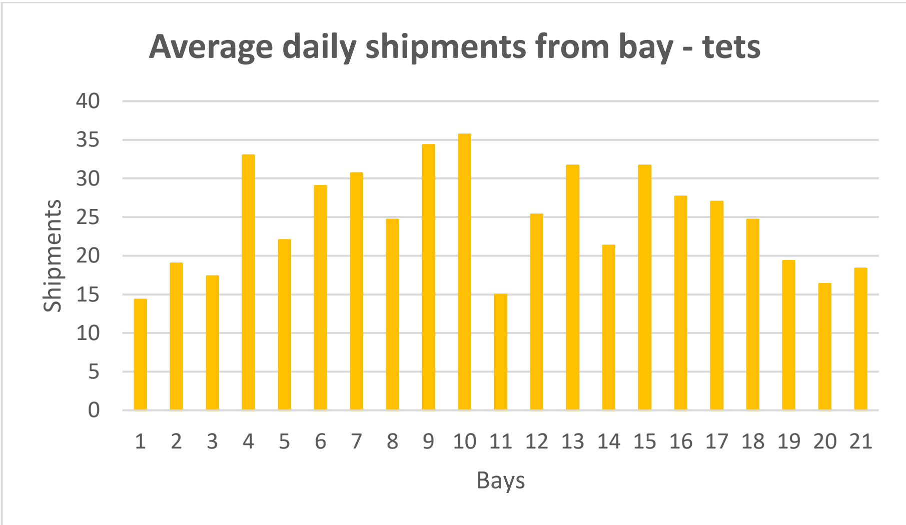


Figure 36. Mean time between departure from bay – tets

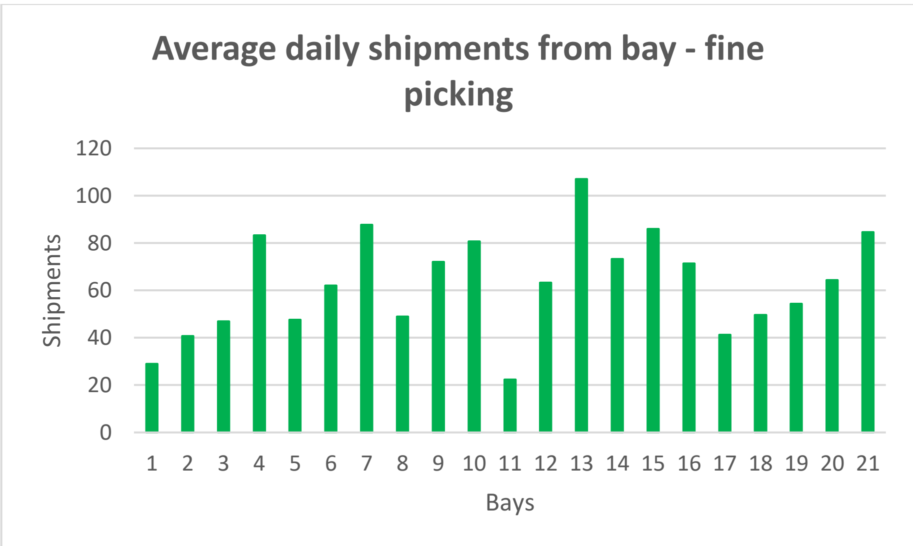


Figure 37. Mean time between departure from bay – fine picking

4.3.4 Utilization

Utilization can be measured in many ways, for the case company warehouse it is considered in terms of storage capacity, picking locations, and volume or resource utilization. Starting with the storage capacity. As the previous section dictated, the warehouse uses multiple storage types. The exact total storage capacity is a somewhat fluent figure, as the warehouse continuously adjusts. Here the total capacity is based on a snapshot taken upon currently writing this, mid-May 2021. Using this snapshot is a simplification, and while it may not fully represent the average, mid-May is a normal week i.e., not influenced by external factors or seasonality, and should not be too far off from expected capacity figures. The snapshot takes into consideration each material flow channel, as shown in Table 11, as well as a summarizing total. The storage capacity utilization figures vary from about 69 % to 82 % between the flows, landing on a total of just above 70 %. This total figure is heavily influenced by the crates flow capacity though, which constitutes larger quantities since its SKUs are smaller. In the extremes, a pallet for the fine picking flow can fit between 27 minimum to 27000 cartons maximum (where a carton can contain multiple items), though the more common amount stored on a pallet is either about 600 or 1200 cartons. Tets have room for 72-240 single cartons, though more commonly 90 or 120. While a crate in the crates flow fits just 12 or 15 single cartons depending on size. The total figure is therefore not completely just to the actual storage capacity utilization rate. Pallets are stored throughout the warehouse in various ways, for instance in the AS/RS cranes, on floor storage by the inbound section, or on static shelves in the secluded area by inbound bay F called the *cold room*. Storage capacity for the tets flow is divided into internal and external capacity. The internal capacity holds 1800 tets and is stored in the large-scale gravity flow racks or on intermediary storage locations close by, while external with a capacity of 1500 tets are stored in the newly opened area north of the AS/RS cranes. Crates are stored in the Multipickers proximity or on intermediary storage points awaiting put-away.

Table 11. Storage capacity utilization

Storage capacity	Snapshot	Total capacity	Utilization
Fine picking (Pallets)	3467	4216	0,82
Tets	2503	3300	0,76
Crates	10223	14855	0,69
Total	16193	22371	0,72

Moving on to the utilization of the picking locations for each of the main material flow channels, the utilization rates vary from 86 % for fine picking, to 98 % for tets, and finally 100 % for crates. Table 12 shows these three rates, and the utilization rates for the three subsections in the fine picking flow, the CMS, AS/RS, and LF area. Fine picking has the most picking locations at the warehouse, consisting of 821 as measured in the snapshot. The CMS statically makes out 240 of these, each of which are in use (might be temporary exceptions or long periods of time before a slot is used). Following section, the AS/RS cranes consist of the most picking locations in the flow. Out of the 408 measured picking locations (8 cranes with 26 picking locations on its east side and 25 west), 391 are used in the snapshot. This current figure of 17 unused picking locations fluctuates but is always kept between 10-20. The reason for this is to act as safety capacity if, for instance, an SKU were to have a significant demand increase over a period, allowing it two spread out over an additional picking location. The number of picking locations in the LF area is the most fluent out of the three sections. There is usually available capacity for this section, in the snapshot, there are, as Table 12 indicates, 76 picking locations used out of the currently measured 173 total locations. This LF area is essentially the only part of the warehouse with a poor picking location utilization figure, which is due to the types of SKUs stored in the area, which if following an ABC-skew would be the C-classified items.

Table 12. Picking locations utilization

Picking locations	Used picking locations	Total picking locations	Utilization
Fine picking	707	821	0,86
CMS	*240*	*240*	*1*
AS/RS	*391*	*408*	*0,96*
LF	*76*	*173*	*0,44*
Tets	47	48	0,98
Crates	3	3	1

Continuing to the tets flow channel, the utilization rate is essentially 100 %. As a precaution, one or so picking lanes might be left unoccupied for safety capacity, which is why Table 12 has 47 used out of the total 48 picking lanes. Crates have a fully mechanized picking process and do therefore in a sense not really have any picking locations. The three listed in Table 12 are the three zones in which picked orders are moved towards by a conveyor to then be picked by a counterbalanced forklift. All of these are essentially always in use, the only exception is if one of the three Multipick systems were to malfunction, which according to the interviewees rarely happens.

Besides the storage capacity and picking locations, the volume utilization is also of significance to the case company warehouse. Maintaining a constant temperature of 4°C in a warehouse with an area of 14500m^2 and height of 7,7 meters for all but the far east section is demanding and costly, especially during summertime with warmer outside temperature. Not letting any cubic meters go to waste is thus desirable from an efficiency standpoint. However, significant portions of the vertical areas for the regions with 7,7 meters height are unused. Excluding the fine picking cranes and some parts of the KPV-square, it is mostly floor storage used for the 7,7-meter-high area. Marked in Figure 38 are areas where significant portions of the height of the warehouse are left unused, including both the 7,7 and 4,5-meters high areas. The image shows an approximation, and aisle space must be considered. However, the northbound area by the AS/RS cranes, portions of the LF area, parts of the KPV-square, and most of the area by the rolling plane (including the tets gravity flow storage), are all parts where floor storage is mainly used and thus the vertical utilization is poor. With volume utilization being an, according to the interviews, important KPI for the warehouse, the vertical usage is a figure which the warehouse seeks to improve.

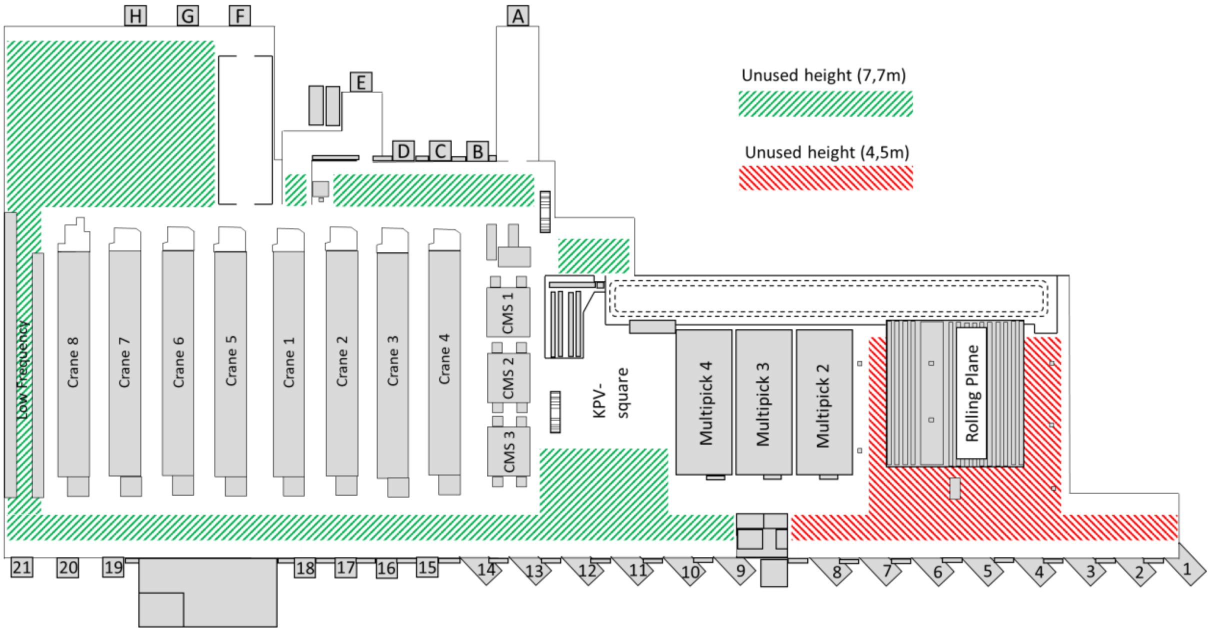


Figure 38. Areas with unused vertical space in the warehouse

4.3.5 Service level

One of the most significant KPIs of the warehouse is expressly the on-time delivery accuracy to bay, which is measured continuously. A sample week to showcase the performance measured over the weekdays can be found in Table 13. On a daily basis, the warehouse strives to achieve an on-time delivery accuracy to bay of 83 %. For this sample week, there is a stable and strong performance for the first four days, with the Friday being an outlier. The reason for Friday's poor result in this instance was mainly due to a delay with the 10:30 orderwave. An important note here is that there is also a safety time of 45min on top of this measure. Hence, even if the target value is not met, it is still most likely going to depart on-time from the warehouse from the customers' perspective.

Table 13. Single week example of on-time delivery to bay performance

W12	Monday	Tuesday	Wednesday	Thursday	Friday	Average
Target 83 %	84	75	88	81	39	73,4

This KPI is also measured on a weekly basis, however with a target of 80 % on average for the whole week. The sample week in Table 13 is as-is not fulfilling this target for the weekdays because of the Friday, but the final measure will also include the weekend figures. Figure 39 shows to the left the second part of 2020's performance for the warehouse, and to the right the year of 2021 thus far. The green color indicates that the case company warehouse reached or surpassed the weekly target of an 80 % average on-time delivery to bay, the red color indicates that they did not reach that high. The left diagram reaches as high as 89 % in week 50 and as low as 69 % in weeks 34 and 52, with an average of about 77,6 %. Whilst the right one has reached its peak at 83 % and its low at 74 %, averaging about 78,1 %, just shy of the target value counting total average.

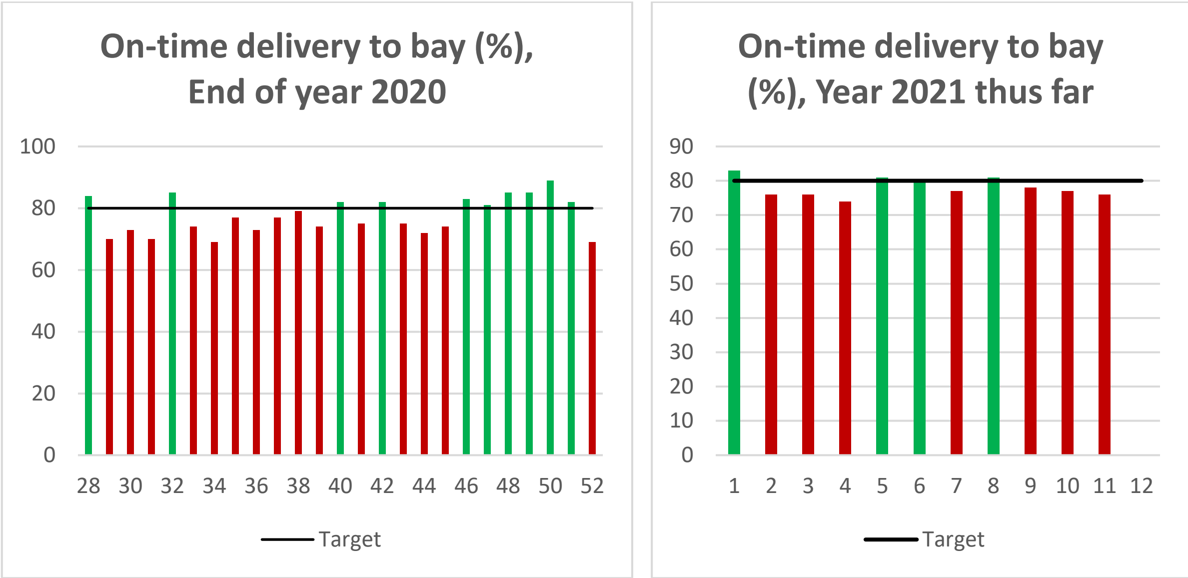


Figure 39. On-time delivery accuracy to bay

Looking at customer complaints averages, based on data from the month of February 2021 the fine picking flow accounts for about 85-90 % of the total amount of complaints being made, and tets essentially covers the rest, as indicated by Figure 40. Considering the amounts of orders sent and their weights, it is not surprising that these two generate the most complaints, particularly the fine picking flow channel with its order complexities. Crates, the third main flow channel, only accounts for a minuscule number of complaints and is hence excluded. Fine picking has about 5-6 items listed per complaint (13 items per complaint if including EUP) and tets about 9. The types of complaints filed can essentially be boiled down to either quality deficiencies e.g., leaking cartons or faulty expiration date, or missing items in the delivery (mainly due to picking errors). Both material flow channels have damaged goods as their primary source of complaint, accounting for about half of it. The types of filed complaints are similar for the two flows in terms of distribution, though with two outliers. One of which is that an item is completely missing, this is one of the most common complaints filed for fine picking, however not for tets. The other one is quality deficiencies in the packaging. This is common for both, however for tets it is the most common complaint filed whilst for fine picking it is a few stances down.

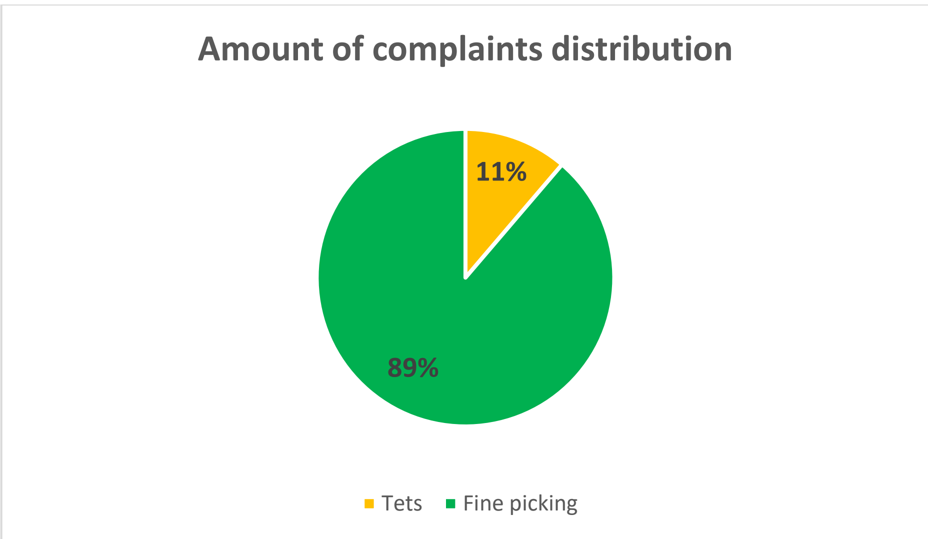


Figure 40. Complaint distribution

4.4 Identified problems

The empirical findings indicate that several of what constitutes wastes according to the literature could be identified at the investigated case company. By applying the VSM technique and mapping out the current state of the three material flow channels, some wastes could be determinately identified. Since the seven wastes in the Lean philosophy are formulated to fit a manufacturing context, the translation provided by Abushaikha, Salhieh and Towers (2018) and Abhishek and Pratap (2020) is adopted to better fit the warehousing environment, as seen in Table 14. The main flow channels show mainly symptoms of needless transport, inappropriate processing, redundant stock, and defects. As Table 14 shows, the other wastes are not highlighted by the empirical findings.

Table 14. Identified wastes

Waste	Meaning	Identified
Overproduction	Picking or preparing orders before being ordered downstream (congestion)	
Waiting	Inefficient time usage leading to stoppage of inventory movement or a period of inactivity	
Needless transport	Transportation without real utility	X
Inappropriate processing	Process step which does not contribute any value (double actions)	X
Redundant stock	Overproduction upstream leading to excess stock; Storing safety or buffer stock in the warehouse	X
Needless motion	Worker making redundant actions which are avoidable	
Defects	Dispatched orders that do not conform to requirement	X

Needless transports are here mainly considering unnecessarily long transport distances in the warehouse, inappropriate processing refers to the double actions transpiring, the redundant stock considers both unnecessarily high inventory levels leading to spillage due to expired products because they cannot be picked in time and the intermediary stocking points found in each flow channel, and defects regard received customer complaints and spillage from the warehousing operations. Each of these wastes is investigated further for each flow channel in the analysis section.

Besides identified wastes from the current state mapping of the material flows, there are some other significant efficiency-related issues found at the case company warehouse. Space utilization is one of these, not in terms of picking locations, but volume utilization. The full height of the warehouse is not being fully utilized, especially regarding the newly opened area north of the fine picking flows by the inbound. High utilization is a prominent characteristic of an efficient warehouse, especially with a chilled storage facility where the unused area becomes significantly more costly in terms of energy wastage. Another problem that hinders the overall efficiency of the warehouse is the workload imbalance. The activity profile shows that there are great differences between certain hours during each workday that is causing both surpluses and shortages in terms of worker demand. To this, there are also many shift types employed at the warehouse to help the balancing, which is costly.

The current central planning configuration prevents proper workforce planning on a regional level since order data is not available until the first orderwave is released to the plant at 10:30. This structure forces an increased need for flexible workers and a need for agency firms, which is expensive. Another issue is the WMS used at the warehouse, which is hindering the case company warehouse from being unified with the rest of the organization. Since they use a different system than the other subsidiaries, there are sometimes issues arising when widespread changes are made related to the information systems. Lastly, there are many different truck types used at the case company warehouse. Abiding by an overall standard would be more in tune with an efficiency orientation. There are some additional issues to these that could be further investigated based on the empirical findings, such as the number of single-line orders on the Sunday for the fine picking flow channel, for instance, however for the sake of time, it is excluded in this thesis.

5 Analysis

This section presents the analysis of the conducted study. It takes inputs from the literary findings and empirical findings into consideration to come up with remedies for the identified problems. The section is split into two segments. Where the first one comprises the future state mapping of the warehouse and ends on a notion about advancing the Lean journey. The second segment considers miscellaneous efficiency remedies for the warehouse and what implications made suggestions have in terms of achieving strategic fit.

5.1 Mapping out the future state of the warehouse

The current state mapping for each of the material flow channels left room for improvements. Each flow channel is convicted with its own set of issues, though many can be derived from similar aspects. The following subsections dwell deeper into the issues found for each flow channel and present a future state configuration as an attainable target for the case company warehouse. The focus lies on removing the identified wastes within each system to obtain a Lean value stream.

5.1.1 Fine picking

The fine picking material flow channel accounts for the majority of outgoing customer orders, according to the empirical findings. Seeking improvements to this flow is therefore imperative for the entire warehouse performance. Strictly reviewing the activities in the current state VSM, shown at the top in Figure 41, there are objectively needless ones. Blocks 2, 6, and 7 are all redundant intermediary stocking points in the flow and should be removed. Looking first into block 2, the step between inbound and put-away, this serves no value for the throughput other than at best being supporting reserve capacity for pallets when the cranes are fully occupied. Removing this step would induce a more continuous flow of goods and entail that pallets are, after receiving and scanning, directly transported into the cranes receiving stations. Since, according to the receiving data, multiple pallets arrive at the same time, manual direct insertion would be infeasible, considering that the amount delivered surpasses the current number of counterbalanced trucks available. A solution would mean to have more trucks and operators ready, though there is still the constraint of the number of cranes receiving stations. A more apt solution, especially with the significant extent of mechanization at the warehouse, would be to install an automatic solution that inserts pallets directly into the slots. This could be accomplished by a conveyor system of sort on which pallets are placed just as they enter the warehouse, similar to the carousel system in the put-away operations for tets and crates. A side issue for the fine picking flow that hinders this though, is that the AS/RS cranes are unable to transport pallets in-between one another. Entailing that when a pallet is placed in the wrong crane, it must be removed manually by a counterbalanced forklift. This does not happen frequently, but when it does it causes major issues from a Lean perspective. In the sense that needless transport in terms of double handling is required and that it also disrupts the picking routes while it is being removed. Before installing any solution of automatic insertion into the cranes this issue must be resolved. Based on conducted root cause analysis, see Appendix E, two possible methods of doing so are unveiled either to have pallets scanned more thoroughly on the conveyor system before they enter the receiving area, or to install within the AS/RS system a track that can transport pallets in-between the different cranes. For which a solution, similar to what was proposed by Hu and Chang (2010) in the literature section about automation, that allows for three-dimensional movement by having an auto-access multilevel conveying device integrated into the AS/RS could work. The latter of the two would be a more expensive solution but would be relevant regardless of whether an automatic insertion solution is invested in or not. By removing block 2, the inbound and put-away activities would merge into one in the VSM, as the description at the bottom in Figure 41 states.

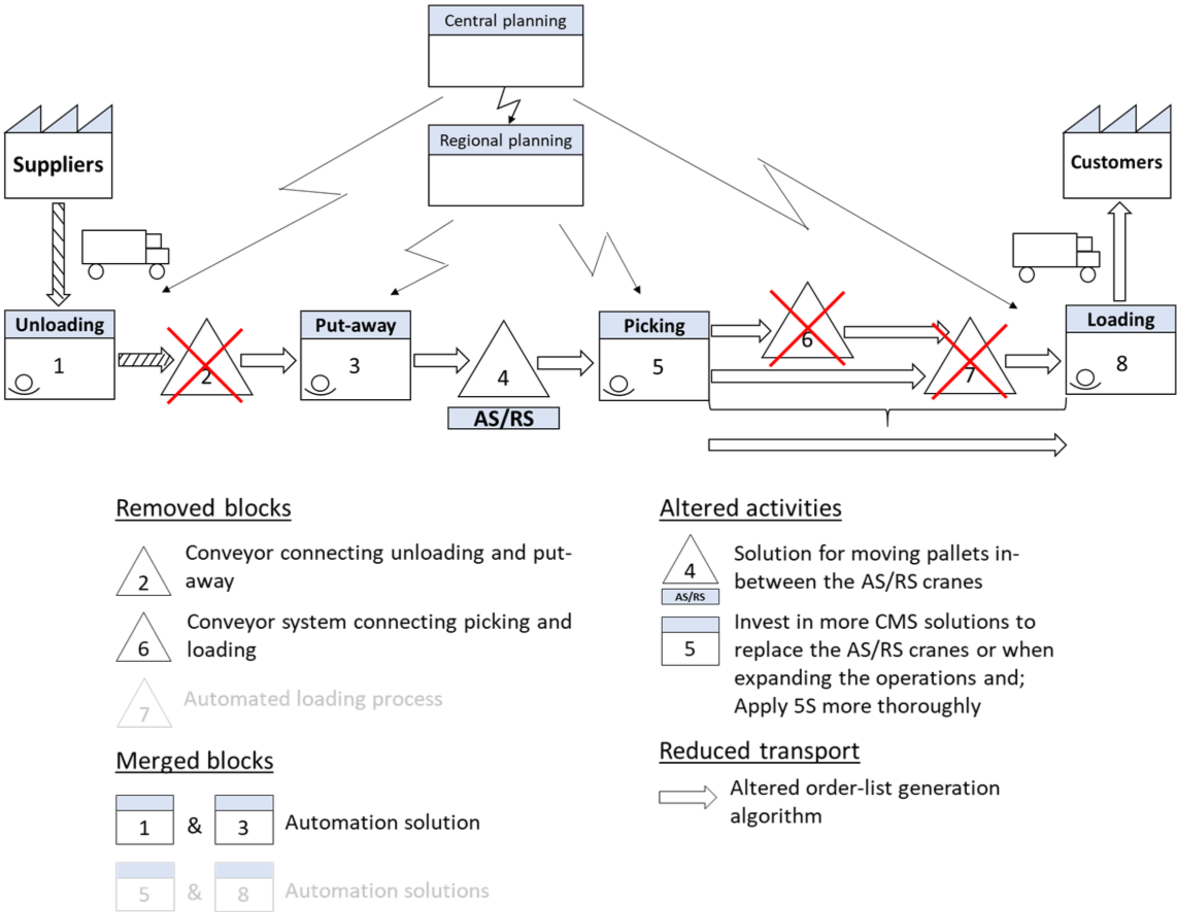


Figure 41. VSM analysis – fine picking

Moving on to block 5 in the current state VSM, the picking operation is a time-consuming activity for the flow and with its high volumes should be made as efficient as possible. Based on the figures from the picking times, it is more efficient to make picks from the CMS than the pallet locations at the AS/RS crane systems. Something which is in tune with literature and common logic, in that the higher picking density the lesser time spent, accordingly with Bartholdi and Hackman (2019). Thus, implementing more CMS systems would be advantageous, whenever the old cranes need subsidizing or when the need for an additional one emerges. Another noteworthy aspect of this flow is the defects it accounts for. Both in the form of spillage and customer complaints, there is room for improvements. As the root cause analysis in Appendix E shows, some of it is beyond the hands of the warehousing department, for instance, products that arrive with poor packaging quality or damaged goods caused by the distribution department. However, some of the defects are derived from the warehousing unit. To short-sighted solution to which could be solved by increased visual inspections in the flow channel, either by the pickers or put extra strain on the distribution unit, which has the responsibility towards the customer. Another approach could be to thoroughly utilize Lean tools such as 5S or SOP, the former of which they are currently using. 5S and SOP emphasize continuous improvements of work standards, and by working with it errors made by pickers in terms of damaging goods will be reduced. Poka-yoke or mistake-proofing solutions to the operation could also be further applied to ensure reduced defects and help reduce customer complaints. Otherwise, since the defects are at least partly related to quality defects, some *quality control (QC)* tools could perhaps be implemented to monitor the process. For starters, the seven basic tools of quality by Ishikawa (1985) could be reviewed, after which more advanced quality tools could be considered as seem fit.

Looking at blocks 6 and 7 in Figure 41, they should both be removed in accordance with Lean Thinking. However, since block 7 is the final step for the warehousing unit before the distribution unit and the truckdrivers take over the responsibility, it will remain untouched for the upcoming recommendations. Otherwise, it would entail a suggestion of direct loading of picked orders onto the trucks, which with the current configuration might cause more problems than it would solve. The other buffer location, block 6 in Figure 41, should be removed though. Its sole purpose is as a waiting area to avoid having low picking trucks traveling to bays 1-8. Pickers do however occasionally place picked orders there destined for bays 9-21. The reason for this is typically that it is full at the bay dispatch zone or human error. Needless to say, this block is a complete waste from a Lean Thinking point of view and should be removed. Altering the algorithm that dispositions the drop-offs of orders or the generation of order-lists, so that those with many fine picking lists depart from the higher numbered bays (9-21), would reduce the need for block 6 since fewer fine picking orders would be allocated to bays 1-8. The bay activity findings dictate that there are available time slots for all bays, therefore modifying the allocations should be feasible. If hypothetically both blocks 6 and 7 were to be removed, it would entail a merger of blocks 5 and 8. Figure 41 feature this hypothetical, but since block 7 is disregarded, they are both faded in the description.

Besides these inventory points, some needless transportations need revising. The traveling distance to bay is on average about 100 meters for fine picking. Depending on where the route end, the shortest distance to bay is around 10-15 meters, only made feasible for bays 16-21. The longest distance is a route that ends at the LF area and is destined for bay 1, which with the intermediate storage point at the KPV-square makes it about 240 meters. This entails that customer orders containing many fine picking order-lists should be dispatching from bays 16-21 and have as few as possible going to low numbered bays, especially bays 1-2. Thus, also opting for an allocation of fine picking orders going to the high numbered bays. The displayed MTBD for the bays in the activity profile shows that 21 bays are excessive for the warehouse, considering the average times between departures. With the fine picking flows significance in terms of outgoing orders (60 % of the total), bays 1-2 (potentially even more than those) could without any damming risks be closed to reduce the average distances to bay in the warehouse.

The points brought up here for fine picking are all meant to improve efficiency and reduce wastes. The impact of and reason for these points, considering the classic seven wastes in Lean, can be seen in Table 15. Needless transports, inappropriate processing, redundant stock, and defects are all impacted for the reasons discussed prior and stated in the table. Indirectly all seven might be impacted in a positive sense, however some are unconfirmable by this analysis and thus labeled with an indifferent impact even though that might not be the case.

Table 15. The alterations impact on wastes – fine picking

Waste	Impact	Reason
Overproduction	Indifferent*	-
Waiting	Indifferent*	-
Needless transport	Reduced	Altered order-list generation algorithm
Inappropriate processing	Reduced	Solution to move pallets in between the AS/RS cranes (also 5S/SOP)
Redundant stock	Reduced	Removed stock points
Needless motion	Indifferent*	-
Defects	Reduced	Application of Lean tools and practices (QC)

*Potentially reduced or improved.

5.1.2 Tets

The current state mapping of the tets material flow channel shows that there are wastes in the system and that blocks 2, 3, 4, 8, and 9 in Figure 42 should all be removed to achieve a more continuous flow. As explained in the empirical findings, the SKUs have two paths leading up to the put-away. In one of them, where the goods come from the in-house production facility, improvements are limited. However, the intermediary point before it is picked up by the carousel system is a needless inventory point. This point can be avoided by having improved timing between the system controlling the conveyor leading out from the production facility and that for the carousel, so that just as it enters the warehouse premise is immediately picked up by the carousel system and placed into storage. This would however be difficult since they run on different information systems and make for a minuscule difference since the average waiting period for the SKUs is relatively low. Goods coming from the second path however have more prominent improvement possibilities. Instead of having the storage points in blocks 2 and 3, just as for the fine picking flow, an automation solution transporting the goods directly from inbound, after scanning, to the receiving plate of the carousel system would be an appropriate addition to the flow. This would entail in Figure 42 that blocks 1 and 5 will merge as one. The alternative would be to have the counterbalanced trucks transport the pallets to the put-away immediately upon arrival, which might be feasible for this flow since there are fewer tets received than pallets, however doubtful.

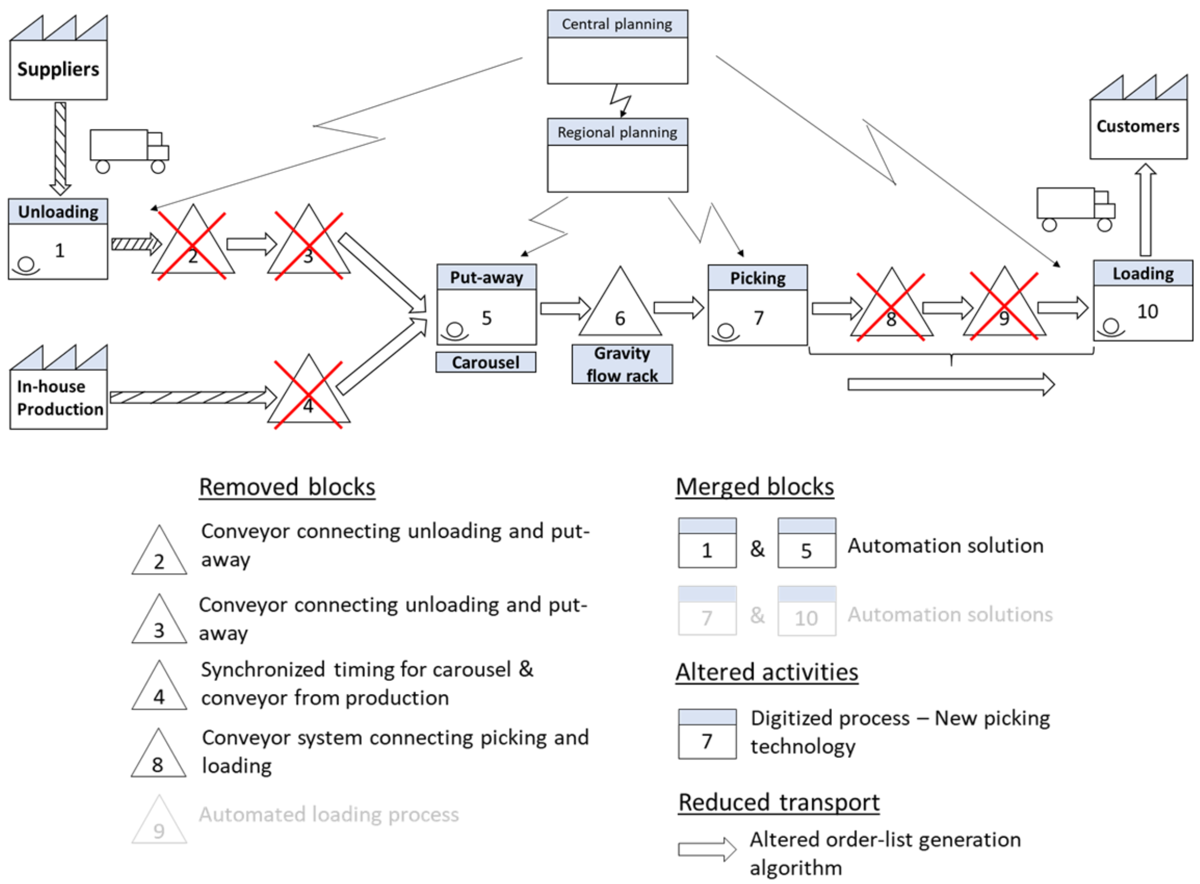


Figure 42. VSM analysis – tets

In Figure 42, the picking activity or block 7 has a significantly longer operation time than fine picking. Efficiency improvements to which is therefore not as impactful to the overall performance since it accounts for a significantly lesser share of outgoing orders. However, the defects waste here is of relevance. While certainly not as frequent as for fine picking, a complaint here accounts for more items on average and is thus more expensive, since one SKU for tets is the entire crate. Customer complaints on goods from this material flow channel have a significant monetary impact on the backorder cost KPI. One approach to reducing this would be a form of mistake-proofing. Since the flow is lagging in digitization, with it having hardcopies printed for orders, applying new technology, perhaps visual picking or similar, could help mistake-proofing the picking process and the pursuit of a better average KPI score.

After the picking, there are two intermediary inventory points of concern in Figure 42, with block 9 just as for the fine picking block 7 landing slightly outside the warehouse scope and is thus overlooked for any final recommendations. The other point, block 8 is a waiting area for a picked order for a counterbalanced truck to come and pick it up, and then drop it off at the designated bay. A conveyor solution transporting the tets directly to the right dispatch zones would be a preferable solution. If combined with an automated loading process, it would entail that there are no storage points between 7 and 10, and thus resulting in a merger of the two activities. However, this merger and the removal of block 9 are both faded in the description, since accomplishing these actions would entail breaking the boundary of the scope of this thesis. There are some needless transportation distances at this stage of the flow though. With the rolling plane being located at the far east wing of the warehouse, it is a long traveling distance to the farthest western bays i.e., 19-21. If a solution with the order-generation algorithm were implemented, as suggested in the previous subsection, the number of customer orders containing goods from the tets flow would advantageously be allocated to bays 1-11 (or 3-11 if bays 1 and 2 are closed). The direct opposite of the fine picking flow, ensuring that they do not intervene with one another.

These suggestions all have the intention to reduce wastes in the tets material flow channel. Relating to the seven wastes in the Lean philosophy, with the translation to fit a warehousing context, the argued points of removing/merging blocks, altering activities, and reducing transports results in direct reduction of needless transport, defects, and potentially even elimination of redundant stock in the flow. Inappropriate processing is also indirectly reduced because of the modified movement of goods. Table 16 shows the impact on the seven wastes with stated reason.

Table 16. The alterations impact on wastes – tets

Waste	Impact	Reason
Overproduction	Indifferent	-
Waiting	Indifferent*	-
Needless transport	Reduced	Altered order-list generation algorithm
Inappropriate processing	Indirectly reduced	Modified/eliminated movement of goods
Redundant stock	Reduced	Removed stock points
Needless motion	Indifferent*	-
Defects	Reduced	Digitized picking process/ new technology

*Potentially reduced or improved.

5.1.3 Crates

For the third and most mechanized main material flow channel, the issues essentially coincide with those for tets since the two flows share many process steps. Thus, suggestions about automating the movement of goods from inbound to the carousel are identical here. The picking process itself for this flow is low on the tier list of needing improvement suggestions, considering the flow channels records. Differences here to the tets flow lies in the steps after picking, where the geographical position of the flow channel differs. This in turn makes for different distances to bays and best allocation. While it for tets is to transport to bays 1-11, it is for the crates flow between 5-14, with slight differences depending on which of the three Multipick overhead crane systems the goods are picked from. Therefore, it would again be advantageous to review the order-list generation algorithm and allocate orders with many crates loads to the preferential dispatch areas, to reduce the amount of transportation waste.

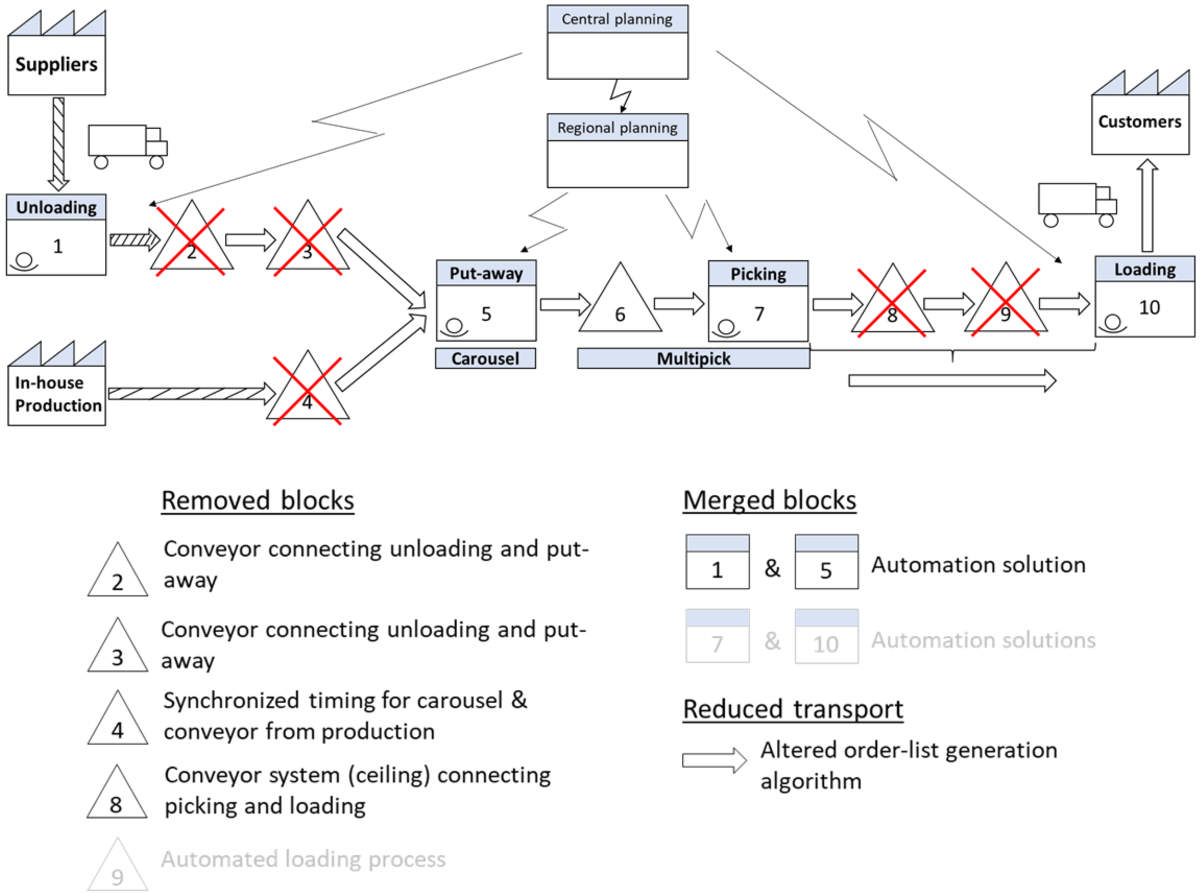


Figure 43. VSM analysis – crates

Besides this, considering the VSM for the flow in Figure 43, there are two intermediate storage points in block 8 and 9, that constitutes as waste. If removed, it would entail direct movement of goods to the dispatch zones for block 8 and an automated loading process for block 9. Though again with the last step before loading, it is excluded from any further recommendations and therefore faded in the description in Figure 43. For block 8, there might be an option for installing a conveyor/carousel type system in the ceiling. This would ensure that it does not interfere in the crossing of paths with entities from other channels and would increase the volume utilization rate of the facility. Installing either a ceiling-mounted carousel system or a normal one would make this flow channel completely mechanized (excluding block 9) if also an automation solution is implemented to remove blocks 2 and 3. The root cause analysis in Appendix E showed that there is an additional concern regarding the load carrier for this flow. When stacked six high it tips easily, the plastic crate design should therefore be revised, for it to be a more robust carrier and avoid needless spillage.

A summary covering which wastes are addressed by the actions argued can be found in Table 17. For this flow channel, out of the seven of what Lean categorize as wastes, needless transport and redundant stock are directly reduced when making the alterations previously mentioned. Inappropriate processing is also indirectly reduced because of the modified movement of goods.

Table 17. The alterations impact on wastes – crates

Waste	Impact	Reason
Overproduction	Indifferent	-
Waiting	Indifferent*	-
Needless transport	Reduced	Altered order-list generation algorithm
Inappropriate processing	Indirectly reduced	Modified/eliminated movement of goods
Redundant stock	Reduced	Removed stock points
Needless motion	Indifferent*	-
Defects	Indifferent	-

*Potentially reduced or improved.

5.1.4 Advancing the Lean journey

The suggestions derived from the VSM for each material flow channel all point towards more efficient and continuous processes. Reducing average transport distances to bay, reducing the number of defects, eliminating intermittent waiting points, fool-proofing processes, and implementing more automation solutions, are all factors contributing to a more Lean and continuous material flow. Considering the Hayes and Wheelwright (1979) product-process matrix, the investigated case company warehouse is currently located around the proximity of the third stage. They have a broad assortment of items, not quite commodities but there is high standardization in terms of packaging and volumes. The process is within the proximity of the connected line flow as-is. Making the improvements presented in the analysis would move the warehouses positioning within the product-process matrix closer towards the center of the desired diagonal, see Figure 44. Since, if implemented the processes would become more continuous, whilst the product structure remained untouched.

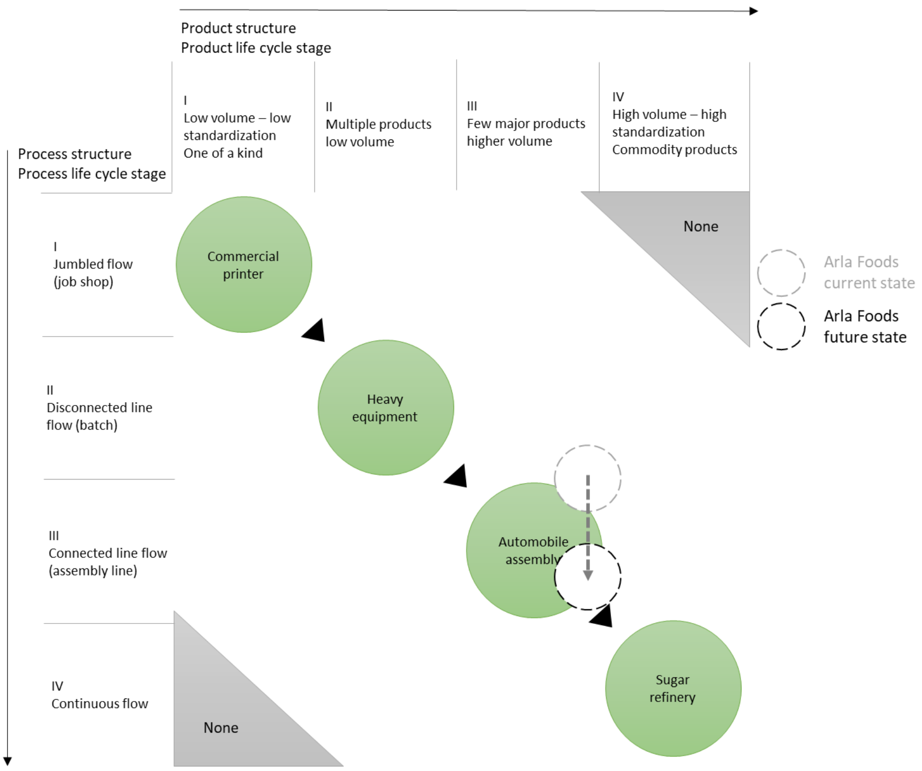


Figure 44. Case company product-process matrix placement, adaptation from Hayes and Wheelwright (1979)

By obtaining more efficient and continuous processes, significant steps towards the journey of becoming Lean are realized. The empirical findings dictate that becoming Lean is the desired state for the case company warehouse, which considering the placement on the product-process matrix is an apt goal setting. Putting the Lean initiatives on hold, as the case company warehouse has done according to the empirical findings, negates the core principles of the philosophy of continuously improving in terms of efficiency. By successively remedying the identified problems from the empirical findings, the forces advocating to continue the Lean journey should out sway those opposing. Considering Figure 45, an adaptation of the Melton (2005) figure, as the listed potential benefits become realized upon implementation, the skepticism and dismay should dissipate progressively and allow the case company to advance their journey of becoming Lean. Reducing or eliminating wastes is one of the fundamentals of the philosophy, and by working with reducing the existing needless transports, inappropriate processing, redundant stock, and defects, substantial progress is made on the journey towards becoming Lean for the case company warehouse.

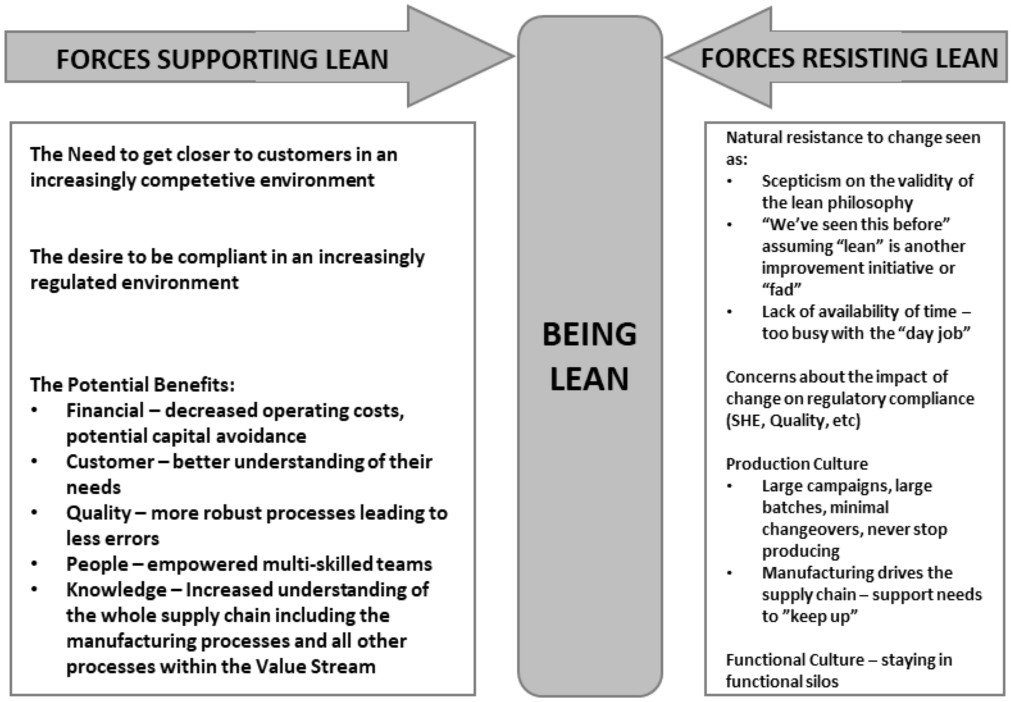


Figure 45. Enhanced forces supporting Lean, adaptation from Melton (2005)

5.2 Miscellaneous warehouse efficiency improvements

Based on the empirical findings there are some other identified efficiency problems to review for the case company warehouse. The four primary ones are linked to the warehouse's volume utilization KPI, equipment used, information systems, and the nature of the contextual factors that is the order and demand characteristics. As mentioned in the summation of the empirical findings, more problems than the analyzed in the following subsection exist but are not as prominent. The following subsections look deeper into the miscellaneous warehouse efficiency problems identified.

5.2.1 Space utilization

An area that received reoccurring attention during the interviews and observations, was space utilization. Regarding the utilization in terms of picking locations and storage capacity, is for most instances a near optimum. There is room for finetuning, but too radical alterations spawn the risk of suboptimization and could potentially create repercussions affecting other areas such as the throughput efficiency. However, in terms of volume utilization, there is room for improvement. Volume utilization is as the empirical findings mentioned, a KPI that is seeing an increasing amount of attention from the case company since it is both a measure of resource efficiency in the warehouse, a concept that if adhering to the Lean philosophy should be high, and that maintaining a temperature of 4°C is costly. Besides the expense of running the warehouse at a constant low temperature, it also puts a strain on energy consumption.

There are several areas where the volume utilization has the potential to be higher. Particularly in terms of vertical utilization, as the root cause analysis in Appendix E unveiled, in areas that do not interfere with any of the main flow channels and where floor storage is used. The most prominent example of this is in the newly opened area north of the AS/RS cranes by the inbound bays F, G, and H. Exception though is the cold room area, marked within brackets in Figure 46, as this area is designated for special products to be shipped to the UK, that has different constraints and is thus secluded in its own caged area. Besides the cold room, this expanded field has an area of about 1300m^2 and uses only floor storage. The clear immediate solution to increasing the utilization rate would be to install single-deep static racks in which to store pallets. Currently, this region is used for the temporary storage of goods moving to one of the three main flow channels. If this remains to be the case, these need fast retrieval and could then be stored on the floor level for easy access. Leaving the vertical space available to act as reserve bulk for the LF items or any other special handling goods.

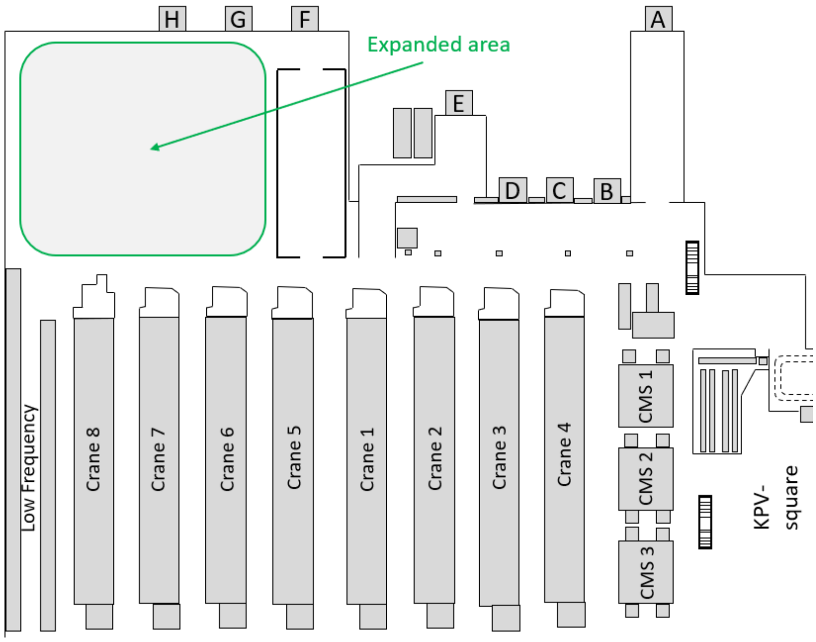


Figure 46. Newly opened expanded warehouse area

Of course, if any solution brought up in the previous section regarding some sort of conveyor system in between the inbound and put-away were to be installed, this area could act as reserving capacity, or if large amounts of pallets arrive simultaneously act as temporary storage. If bays 1 and 2 were to be closed, a discussed alternative in a previous section, this additional space could be utilized for other purposes e.g., storing special handling goods or as utility. A suggestion that was brought up during the interview with the Senior Warehouse Manager was to implement a paternoster system for storing tets instead of using the newly opened area. This would allow for better height utilization and potentially also a better storage alternative for the flow. Besides this, implementing a solution to store tets in the rolling plane 2-3 levels high could help improve the vertical utilization at the 4,5-meters high eastbound area of the warehouse.

5.2.2 Equipment selection

Pointed out in the empirical findings is that there are many trucks of various types used at the case company warehouse. From an efficiency standpoint, it is more beneficial to have a standard set of handling equipment. In general, the selected material handling option is apt for their intended activity, however there are exceptions. The counterbalanced forklifts are something of a misfit in a fully indoor warehouse. Considering their main task is moving pallets or rolling cages, they could be replaced by pallet picking trucks. If more automation solutions were to be implemented in the warehouse as described in the future state mapping section, the need for these trucks will further dissipate. Currently, the counterbalanced forklift is a versatile option and not necessarily the wrong choice, but in moving forward to the desired state they should be phased out to either make for a more standard selection of trucks in the warehouse or removed altogether in a more automated warehouse configuration.

5.2.3 Information system

Based on the empirical findings, the warehouse's current WMS occasionally poses issues for the case company warehouse, since the organization has widely adopted a different system for all subsidiaries and utilizes a central planning structure. This entails that when widespread changes are issued, the current system may not be compatible to implement the initiatives, causing issues as it would require additional resources to ensure applicability. While this current WMS might have been the best suitable option when it was first introduced to the case company about 15 years ago, when the subsidiary was in the forefront and a test subject for more mechanized warehousing operations, and still suffices for the needs of the warehouse today, it would be more apt and Lean for the organization to have a standard system running at all subsidiaries. The literature on Lean emphasizes efficiency and standardized operating procedures throughout the entire organization, this includes the information systems used. Phasing out the current system for the one used at the other subsidiaries would eliminate redundant compatibility issues when wide-scale changes are made in the organization and attest for more Lean Thinking.

5.2.4 Workload balancing

One significant challenge for the case company warehouse mentioned in the interviews was workload balancing. Where the warehouse has, besides their weekend employee pool of extra laborers and use of agency firms, adopted a mid-day shift to help manage the highest daily demand peaks and balance the workload. Running multiple shifts are expensive, a root cause analysis of why this shift is deemed necessary for the current configuration is thus performed and can be found in Appendix E. From which it could be determined that the reason behind the need for extra manpower partly stems from the demand and order characteristics. These fall under the category of contextual factors in accordance with the literature and are aspects that are outside of the short-term control for the management. It is also due to the central planning structure at the organization and the releasing of orders twice a day, at 10:30 and 17:00. This orderwave strategy causes more picks to be made in the expensive afternoon labor period. While the reasoning might have been well-intended when it was implemented, it is certainly causing issues with workflow balance today. The regional warehouse planning unit is unaware of the upcoming daily volumes until the first wave at 10:30 arrives. This makes the planning process difficult and adds to the requirement of flexible workers.

Even out the orders should be a prime objective for the case company and should be addressed to the central planning unit. The differences between the weekdays are beyond the control of the case company warehouse. This structure is linked to how the customers make their orders. Variations during the day can however be changed. Alternatives to alleviate the daily workforce planning can be to either implement an additional orderwave to spread out the releasing of orders or modifying the current release times. This is currently investigated at the case company and should if implemented eliminate the need for an additional shift to manage the peaks. Something which combined with having more picks performed during earlier hours should be of high priority to reduce the labor cost and become more cost-efficient overall.

5.2.5 Approaching the cost-responsiveness efficient frontier

Compiling the suggestions from the previous section about the VSM and this section of miscellaneous efficiency improvements, it is all about improving the warehouse’s efficiency performance. The case company organization seemingly has a Lean orientation throughout and strives to become more cost-efficient without disrupting responsiveness too much. Considering the cost-responsiveness efficient frontier from Chopra and Meindl (2007) about achieving a strategic fit, the organization is located in the lower right proximity. The case company warehouse is geared slightly more towards the right and closer to the frontier than the overall organization, considering their early technology adaptations and current mechanization degree. However, both can afford to become more efficient, or more responsive if so desired. The focus of this study has been oriented around efficiency and made suggestions all intend to make the processes more efficient in various ways e.g., the suggestion for more continuous flows is meant to reduce overall throughput times or lead times, and the increased volume utilization to improve the resource efficiency. A current approximation of the case company warehouse placement in relation to the cost-responsiveness efficient frontier can be seen in Figure 47, where a depiction of where made suggestions move the company is featured. With the clear efficiency focus, it is moved further to the right in the figure, but also a bit further down. Because, as stated in the literature section by Bartholdi and Hackman (2019) about automation, automation is great for achieving their desired purpose and typically, if implemented with the right intent and in a way that avoids suboptimizations, succeeds in making processes more efficient. However, at a cost of flexibility. Moving from more disconnected flows to more continuous will reduce the flexibility of the system. Thus, the movement in Figure 47 ultimately goes southeast. Needless to say, this brings the case company closer towards the desired state along the best supply chains by the frontier. Important to note here is not deviate too much from other subsidiaries, as the holistic perspective is crucial in terms of the competitive strategy for the organization.

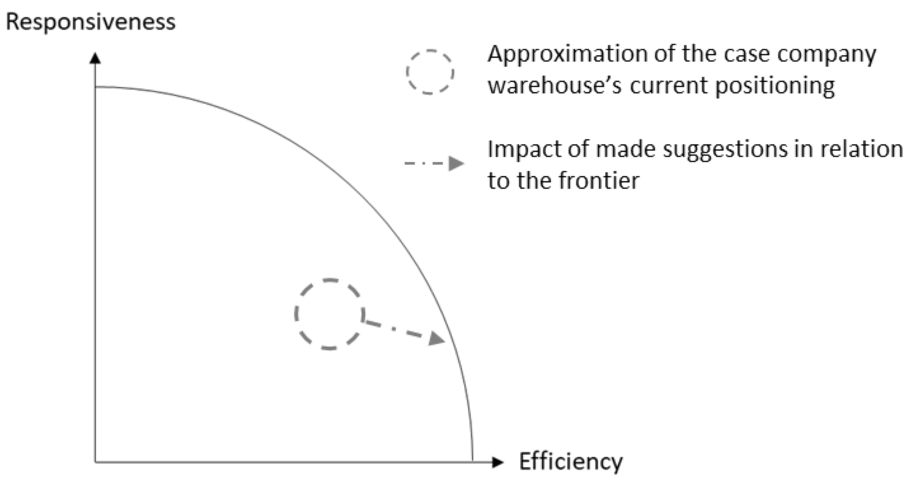


Figure 47. Suggested action’s impact on the case company position in relation to the cost-responsiveness efficient frontier, adaptation from Chopra and Meindl (2007)

6 Recommendation

This section presents the final recommendations to the case company warehouse. The section is divided into two parts, the first one presents the final recommendations and then relates these to each main material flow channel. The second part presents potential future improvements or recommendations. Made recommendations are all derived from the analysis.

6.1 Recommendations for Arla Foods AB

Using the frame of reference an analytical framework was comprised consisting of different models or approaches to apply in the empirical findings and to utilize in the analysis of the case company warehouse. By following the two research objectives of the study, several efficiency-related issues could be identified, and from the analysis remedies for these issues could be contrived. With wastes as the unit of analysis, the focus of the findings and analysis is strictly efficiency-oriented and in correlation also Lean oriented. The nature of the final recommendations is thereby driven by cost- or resource-efficiency. Table 18 shows the final recommendations for the case company warehouse to be considered at the current state, semi-arbitrarily listed in accordance with their significance or impact on the overall warehouse efficiency. The empirical findings dictate that the on-time delivery to bay is the warehouse's most significant KPI. Since this is the case the recommendations that provide shorter lead times and processes with a more continuous flow are seemingly more important. Though considering the strategic fit and the cost-responsiveness efficient frontier from Chopra and Meindl (2007), all cost-efficiency improvements bring them closer to the desired state and are therefore significant.

Each of the recommendations in Table 18 is directly independent of one another, however some may indirectly impact the others. If some of the recommendations were to be too impracticable, expensive, or just infeasible, it should not hinder the rest of them. Recommendations that do depend on a previously recommended course of action are instead featured in the following subsection about future projects. The recommendations have different lasting impacts on the warehouse, but all have efficiency in one form or another as their primary motivator. Some of them require merely time investments, while others a bit more than so. However, they will all theoretically have a positive impact in the long run. The pay-off times vary, though in general, the focus is on a short-to-medium horizon. Each recommended action is presented in Table 18 accompanied with a rationale of why it is recommended and what it will accomplish. The motivation behind the rationales is either to remove wastes, in this case, needless transports, redundant stock, defects, and inappropriate processing (double handling), or to make miscellaneous cost-efficiency improvements, here improving the workload balance, planning capability, and resource efficiency. All recommendations are based on the analysis, that is derived from the literary and empirical findings of the study.

Table 18. Final recommendations for the case company warehouse

No.	Recommended action	Rationale
1	Automation solution (conveyor) between inbound and put-away, also (conveyor, mounted in ceiling if possible) between the counterbalanced forklift picking stations and bays (tets & crates)	Improve efficiency and on-time delivery to bay KPI, also induce more continuous processes
2	Implement algorithm to distribute order lists based on flow channel's distance to bay (fine picking bays 9-21; tets 3-11; crates 5-14)	Reduce needless transportation to bays, and the inappropriate processing in terms of the redundant intermediary storage point at the KPV-square
3	Mediate an altered orderwave structure with the central planning unit e.g., add an additional wave or modify the release times	Improve cost-efficiency and planning capability, it is currently causing too many picks during expensive hours and workload imbalance
4	Close two (or more) bays, ideally bays 1 & 2	Current configuration is causing needless transport distances and MTBD dictates that there is time availability
5	Implement mechanism to move pallets between AS/RS cranes	Mistake-proofing the process to avoid inappropriate processing and disruption of the picking process
6	Install single-deep static racks in newly opened storage area	Improve volume utilization and resource efficiency
7	Invest in apt technology to support tets picking process e.g., visual picking	Mistake-proofing the process and reducing the number of defects/complaints from customer to improve the backorder cost KPI

Executing the recommended actions will impact the daily operations in the warehouse, some more than others. Closing two or more outbound bays and installing racks at the newly opened storage area will have little to no impact on the daily operations. For recommended action number four in Table 18, the warehousing and distribution units must communicate that the bays are no longer active, and the WMS must be adjusted to not designate any departing orders to those bays. Recommended action number six has no major impact on the warehouse operations, it only slightly impacts three of the inbound bays and temporarily the extra buffer capacity, for which there is enough space to move around. Altering the order-list generation algorithm, mediating adjusted order-release times, and implementing new picking technology for the tets flow channel will, depending on execution, not have any significant impact on the daily operations. Recommended actions number two and three will mostly impact the planning operations at the warehouse, and at most cause inconvenience at dispatch until the desired state is reached. New picking technology for the tets flow (recommended action number seven) should not cause any major disruptions depending on the chosen solution. It should be possible to implement it in parallel to the normal operations.

Implementing recommended actions number one and five in Table 18 will have more impact on the daily operations. Installing automation solutions, such as conveyor belts, will restrict the movement of the trucks in the warehouse. Though between inbound and put-away for fine picking it should not have an impact on the picking process, the pickers should have enough turning radius to still carry on the normal serpentine pathing. It will however disrupt the counterbalanced forklifts movement and the put-away operations. Recommended would be to install it gradually to limit the disruption, closing one AS/RS at a time, and reposition picking locations to available slots in other cranes or the LF area. For tets and crates, it is seemingly feasible to install a track from inbound to carousel without interfering with daily operations. Similar logic goes for the other end for tets and crates, between the picking and loading area. Installing a track gradually and ensure enough room for trucks to deposit picked orders. On both ends there may be some interference for the daily operations and recommended would be to do most work during off-hours, meaning Saturday when the warehouse shuts down its operations. Recommended action number five, implementing a mechanism allowing three-dimensional movement in the AS/RS cranes, only affects the fine picking flow directly. Installing a track allowing cross-aisle movement for the S/R units, should be done gradually to not significantly disrupt the picking operations, recommended again is to do most work during the Saturday.

Four out of the seven recommended actions require no significant investment for the case company warehouse. However, recommendations number one, five, and seven in Table 18 do. The case company's willingness to invest in technological advancements is therefore of relevance. At this point, it is important to note that the recommendations in Table 18 have been discussed with case company contacts as the thesis project have been progressing and that this project has been carried out during one full semester. Meaning that the case company has had some time to assess these suggestions as they began to shape and have at this time even started to work on and move forward with a few of them. They have closed outbound bays 1-6 (recommended action number four) and are now using the additional space for extra storage for the tets flow channel, started drafting up a solution to move pallets three-dimensionally in the AS/RS cranes (recommended action number five), started to conceptualize an automation solution between inbound and the AS/RS for the fine picking flow channel (parts of recommended action number one), and begun looking into alternatives to update the picking process for the tets flow channel (recommended action number seven). This entails that the case company warehouse is seemingly more than willing to make investments that further their technological advancement and should have no problems eventually reviewing each of these suggestions. As has been mentioned previously, automation and mechanization are valued highly at the case company warehouse, therefore any recommendations that push them further into that direction is of interest despite longer pay-off times.

It is important to point out though that making recommendations can be easy in theory, but not always as simple to carry out in practice. There are always a lot of variables and constraints to consider when making configurational changes, some of which may have been overlooked or underestimated in making the final recommendations. The recommendations themselves are based on the premise that the fine picking material flow channel is the dominant flow channel, and that there is a consensus to become more efficient and Lean in the company. Listed below are a few bullet points of sensitivity areas that might have a significant impact on made recommendations and that have not been fully vetted due to time constraints or limited access to data.

- Technological advancement can render the recommendations obsolete or unsustainable, referring particularly to investments in automation such as the conveyor systems or the mistake-proofing of the AS/RS cranes.
- Trends in demand can sway and completely alter current conditions, rendering the recommendations less effective. The nature of the industry can also change due to external factors, which could have an impact on the suggestions.
- Budgetary constraints are not a primary variable in the made analysis, this type of constraint could hinder any suggestions or implementation plans.

- Impacts on other sub-functions at the case company might have been underestimated or overlooked in the analysis.
- The central planning unit might not comply with the made suggestions.
- Corporate policies or guidelines could negate the suggestions, there could also be union-related issues in meddling with the workload balance and active shifts.

6.1.1 Fine picking

The final recommendations to the case company warehouse will entail some changes for each of the main material flow channels. Some of them are more affected than others by the seven recommendations. Considering first the fine picking flow channel and relating back to the current state configuration, a few aspects to the flow are affected. Viewed in Figure 48, block 2 in the VSM would be removed by the recommendation to implement an automation solution (conveyor system or similar) between inbound and put-away, as a result, blocks 1 and 3 would also be merged. The main storage (Block 4) would have an altered activity, with the recommendation to install a mechanism that allows three-dimensional movement between the AS/RS cranes to effectively resolve the double handling of misplaced pallets in the cranes. Average transportation distance to bay would be reduced, by adjusting the WMS order-list generation algorithm to favor drop-offs based on the flow channels distance to dispatch bay. The upper part of Figure 48 shows the current state configuration and the lower part the future state configuration of the fine picking flow channel if made recommendations are implemented.

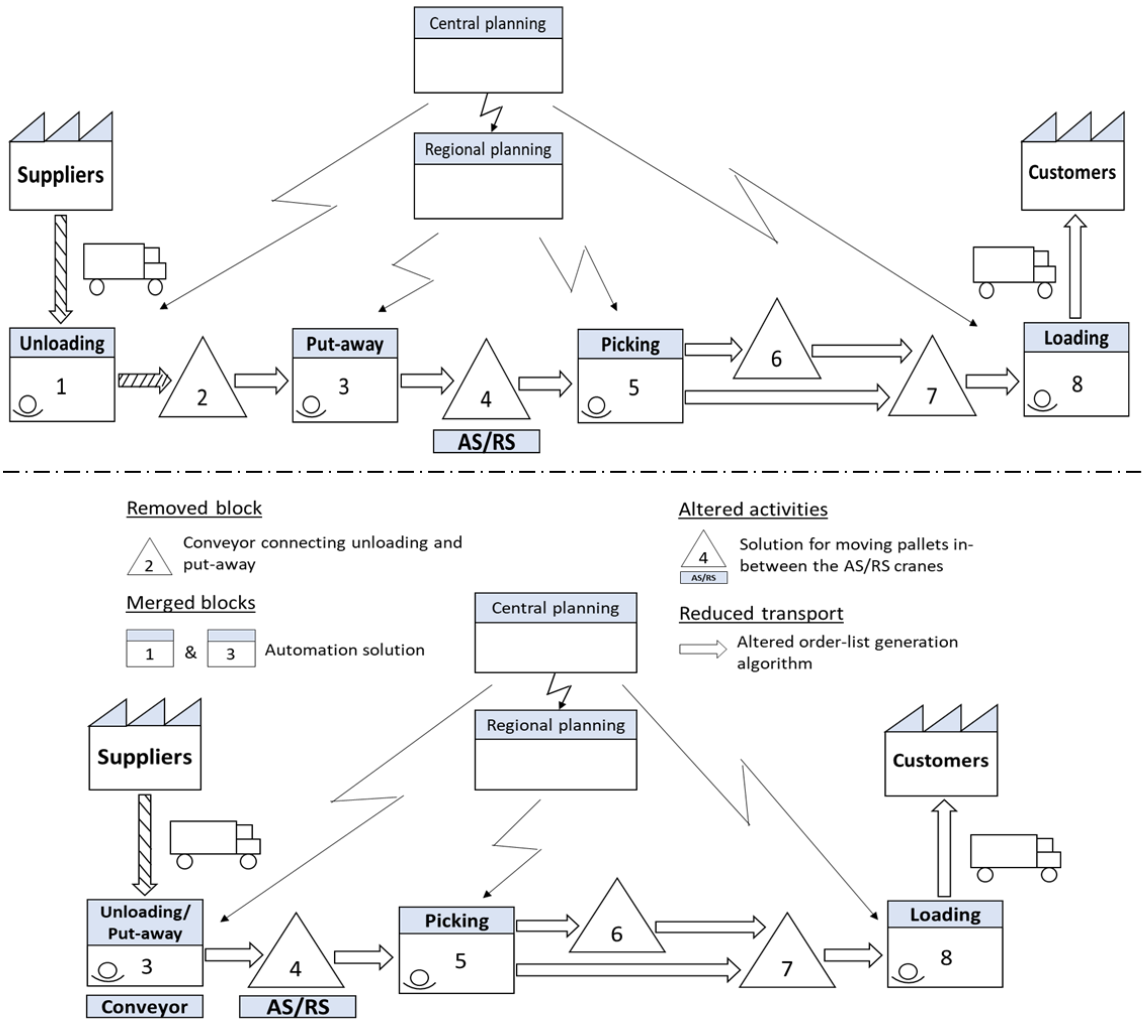


Figure 48. Current to future state configuration – fine picking

6.1.2 Tets

Out of the three main material flow channels, the tets flow will be most affected by the final recommendations. Figure 49 illustrates how the changes would impact the VSM. Blocks 2 and 3 would, similarly to block 2 for fine picking, be removed by recommendation number one to install an automation solution between inbound and put-away, blocks 1 and 5 would also be merged as a result. The picking activity (block 7) would be impacted by the recommendation to invest in apt picking technology (e.g., visual picking) to align the flow with the other two in terms of digitization and to reduce defects (complaints). Transportation would be impacted, just as for fine picking, by the modified order-list generation algorithm. Figure 49 shows in the upper part the current state configuration and in the lower part the future state configuration of the tets flow channel if made recommendations are implemented.

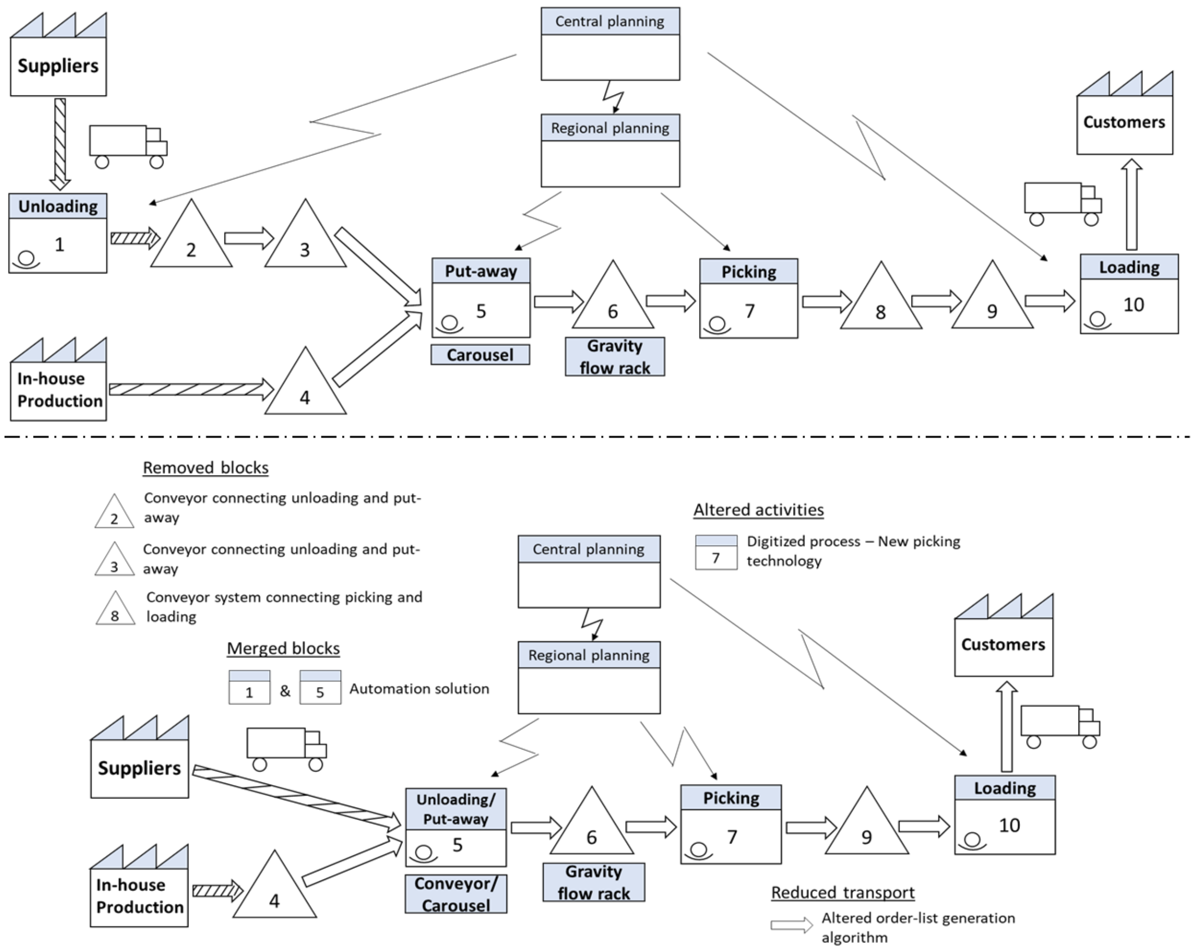


Figure 49. Current state and future state configuration – tets

6.1.3 Crates

The last of the main flow channels, the crates flow, would also be affected if made recommendations are implemented. Here the impact of the recommendations on this flow's VSM, presented in Figure 50, all coincide with the tets flow, as the two flows are for the most part intertwined. Therefore blocks 2, 3, and 8 would be removed from the VSM because of the recommendation to install automation solutions, and in turn, blocks 1 and 5 would be merged. Needless transport would be reduced by a modified order-list generation algorithm. The flow movement below the future state VSM in Figure 50, is adjusted similarly to the tets flow. A difference though lies with the dashed lines, for crates bays 5-14 are most attractive based on distance, the other bays have as a result a dashed line leading up to them. Figure 50 portraits in the upper part the current state configuration and in the lower part the future state configuration of the crates flow channel if made recommendations are implemented. All in all, there are significant differences between this future state after made recommendations and the former current states for the three flows. However, there is still more that can be done, according to made analysis, to achieve more efficient and Lean material flow channels in the future for the case company warehouse.

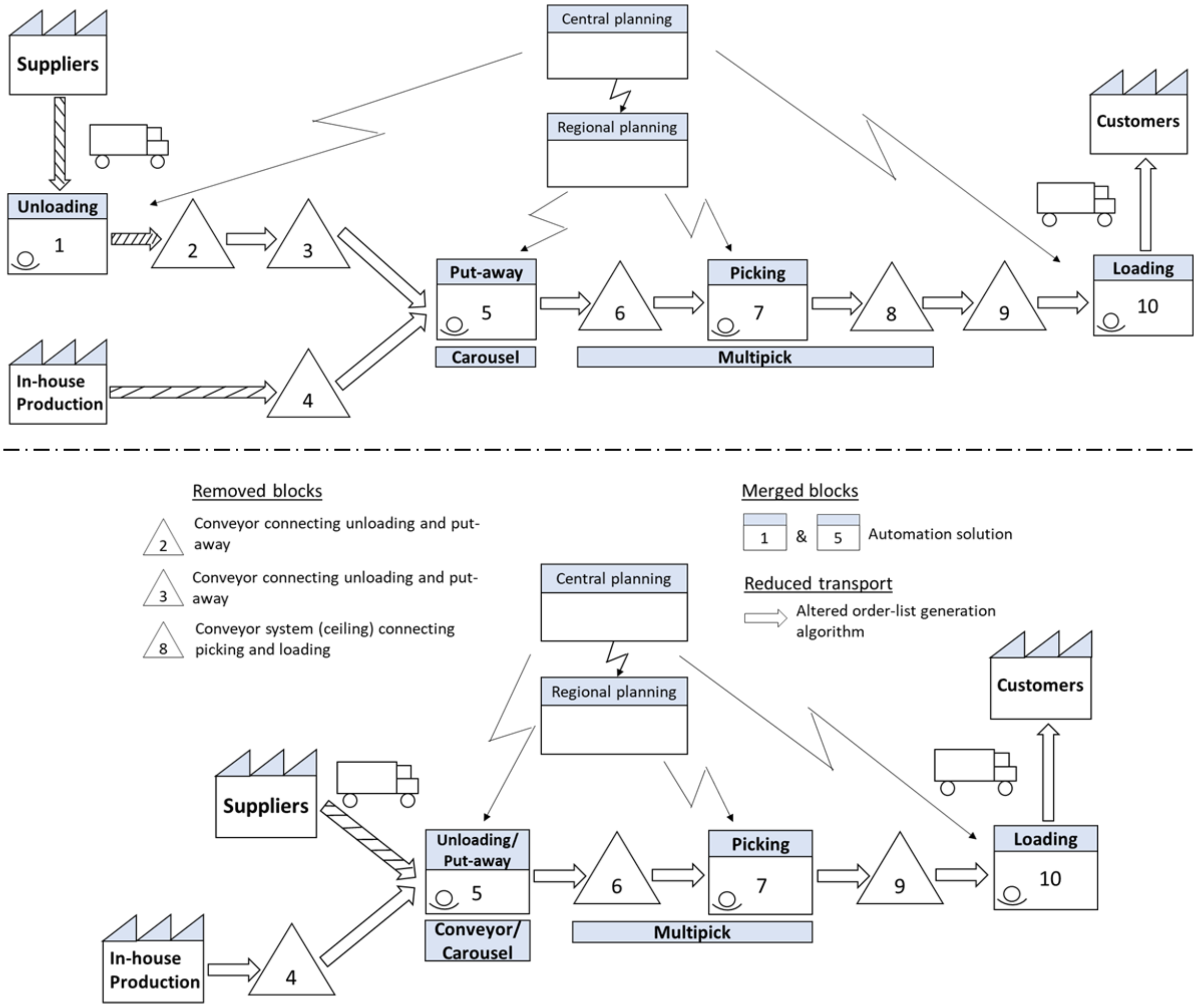


Figure 50. Current state and future state configuration – crates

6.2 Future recommendations

Additional recommendations to consider for the future of the case company warehouse are featured in Table 19. These recommendations, or rather potential improvements, are something that would require further analysis to be recommended at this stage, are currently not relevant, or relies on a previous recommendation to be feasible e.g., point 2 remove the mid-day shift, which probably cannot be achieved without first recommendation number 3 in Table 18 of altering the current orderwave structure. These additional potential improvements are geared towards improving efficiency in the warehouse, either the flowthrough, cost, or other resources. Table 19 presents these in approximate order of importance to the overall efficiency, as some are certainly more impactful than others e.g., point 3 of phasing out the current WMS for a new one compared to point 5 of interchanging trucks.

Table 19. Future potential efficiency improvements for the case company warehouse

No.	Future recommended action	Rationale and potential outcome
1	Remove intermediate storage point at KPV-square	Mentioned in the final recommendations table, this requires altered order-to-bay distribution or reconstruction of the configuration. If this is done, this stocking point is nothing but pure waste in the form of redundant stock and inappropriate processing and should be removed for more efficient processes.
2	Remove the mid-day shift	This depends on if changes towards improving the planning horizon and workload are implemented. If so, this shift is nothing but an added expense and redundant.
3	Phase out current WMS for same as in other subsidiaries	This is a demanding task to execute and is not currently vital. However, it might be in the future, the reason for interchanging is to have a unified information system in the organization. By having different needless extra work to ensure applicability is required when making organization-wide changes
4	Invest in more CMS cranes	The CMS crane is objectively more efficient than the full pallet AS/RS cranes. When or if they need replacing, or for near-to-mid future expansion, more of these or similar systems should be installed to induce a faster picking process.
5	Interchange counterbalanced forklifts	Either switch them out for more suitable option or remove them altogether. Reasoning for is to use a better suited alternative or if automation solutions are implemented remove majority of them as they will be redundant
6	Automation solution at the bay, direct onto the trucks	This is to remove the intermediate storage between finished picked order and loading dock to attain a more continuous flow. This will require close interdepartmental collaboration and between external distributors (not all are Arla trucks). This might be difficult and maybe will only cause additional problems or added work, but if successful would make for a more continuous process.

Finally, an additional remark or recommendation with current and future relevance is to reignite the journey towards becoming Lean. It is not featured in the recommended actions list or future potential improvements list, as it is a separate general topic that serves ongoing relevance. Conducted analysis and applied figures indicate that the Lean philosophy is apt for the industry and the organization. Many of the typical prerequisites or critical success factors to succeed in implementing the concept are fulfilled or has the potential to be, without immense effort. Working towards continuously improving the processes and becoming more efficient will benefit the case company warehouse. It is easy to stop using many of the approaches or to not fully utilize the tools, but in doing so the real benefits of the initiative will not be realized. In one of the interviews, hints towards an organization-wide initiative similar to TPS is dropped, if this were to become reality it would drive the organization down a path to become more efficient. Also, if this would entail increased joint collaboration with customers and suppliers, a more efficient supply chain can be obtained, which would significantly strengthen the whole organization’s competitiveness.

7 Conclusion

This last section presents the conclusions of the study findings. Starting off by revisiting the purpose and research objectives. Subsequently, the study's contributions to theory and limitations are presented. Ending with a discussion about future research options based on the conducted study.

7.1 Addressing the purpose and research objectives

The purpose of this study was to identify efficiency improvements to the investigated warehouse's material flows. Intended to help add on to existing literature about warehousing, a single in-depth case study approach was utilized to sufficiently achieve this purpose. First, current literature and frameworks about warehousing, including configurational aspects and operational performance, were processed. Subsequently, a current state analysis of the investigated warehouse was conducted, using tools such as VSM and activity profiling, to identify problem areas. This followed by analyzing the findings to assess and recommend remedies for the case company. Two research objectives were formulated to help guide the study to achieve this purpose.

RO1: Identify problem areas that hinder the warehouse's efficiency

This first objective was accomplished through the empirical findings, guided by approaches suggested in the literature. The identified problems at the case company warehouse could be sorted into two categories. Where the first consisted of improvements linked to the Lean philosophy and the construct of wastes. Looking at the main material flow channels at the case company warehouse, referred to as fine picking, tets, and crates, four of the classic seven wastes in Lean could be identified using the VSM technique. These wastes were, after translation to fit a warehousing context, redundant stock, inappropriate processing (double handling), defects, and needless transports. Each of these wastes is hindering an efficient process and should be reduced or eliminated. The other identified category of identified efficiency issues in the warehouse is described as miscellaneous efficiency problems. These constitute cost- or resource-efficiency-related issues in the warehouse that does not fully fit into any of the Lean wastes. They were identified by investigating the configurational elements of the warehouse and by reviewing the activity profile. The most prominent miscellaneous problems were related to space utilization (volume), workload imbalance, equipment selection, and information systems. Having identified problem areas that hinder the warehouse's efficiency, the second research objective to develop remedy suggestions could initiate.

RO2: Develop remedy suggestions for the problem areas

Through analyzing the problem areas presented in the empirical findings in accordance with the framework for analysis, the second research objective was obtained. First, the problem areas from the VSM were analyzed. This culminated in a future state configuration after re-mapping the processes with removed wastes for each material flow channel. An analysis of what moving towards the future state would entail, determined that made suggestions would put the case company warehouse closer to the center ideal placement of the diagonal in the Hayes and Wheelwright (1979) product-process matrix. It also showed that by implementing the changes the Lean initiative would gain momentum and enhance the forces pushing the organization to become Lean and reduce those opposing. The miscellaneous efficiency problems were then analyzed in search of remedies. Suitable suggestions based on empirical and literature findings were presented, ending with an analysis of the case company warehouses' altered placement in terms of the cost-responsiveness efficient frontier by Chopra and Meindl (2007). In the search for obtaining strategic fit, suggested actions moved the case company warehouse closer to the frontier via the efficiency improvements, however it also moved it slightly away from it in terms of reduced responsiveness in relation to current state placement.

Based on this analysis final recommendations in the form of remedies to the identified problems from RO1 were made. Seven recommendations were made to be implemented at the earliest convenience, and an additional six in an adjacent future. The seven immediate recommendations are all efficiency-related in terms of either reducing wastes or improving cost- or resource-efficiency. For the main material flow channels, the relevant recommendations are implementing automation solutions to eliminate redundant stock, mistake proofing the processes to reduce inappropriate processing, invest in new technology or supporting mechanisms to reduce the number of defects, altered algorithm to better distribute order lists in terms of flow channel distance to bay, and close two bays (or more) to reduce the needless transports. The additional two suggestions with not a direct impact on the main flow channels consist of modifying the order-release structure to improve the workflow and installing racks to increase the volume utilization.

The six additional potential improvements were presented with the same efficiency focus. Some of these are standalone actions, others reliant on previous actions made. These suggested potential improvements are investing in more automation solutions to the material flow channels, phasing out the current WMS, interchanging or removing the counterbalanced forklifts, invest in more CMS cranes, remove additional redundant stock, and finally remove the mid-day shift. A business case and extensive risk analysis are lacking, and no implementation plan has been forged in detail. But in summation issues have been found and potential remedies in accordance with the empirical and literature findings have been suggested. The purpose of the study to identify efficiency improvements to the material flows to, in turn, help improve the turnover at the most prominent dispatch locations, has been achieved, and the two research objectives guiding the study have been fulfilled.

7.2 Theoretical contributions

This thesis's main theoretical contribution is showing that the Lean philosophy, and more importantly the value stream mapping tool, can be applied in a warehousing context to identify both efficiency problems with a current state configuration and remedies to suggest a future state configuration. The study plays a part in building onto and confirming existing theory within the combined fields of warehousing and Lean. By illustrating what Villareal et al. (2012) argued, that applying the Lean philosophy can result in important efficiency improvements to the processes in a warehouse. It further adds to the Abushaikha, Salhieh and Towers (2018) findings, by showing that reducing wastes has a positive impact on a warehouse's operational and distribution performance in terms of efficiency. Theory about VSM being a key technique for obtaining a Lean warehouse and its positive impact on the overall warehouse efficiency can be further seen from the findings of this study. Much like the concluding findings for the Abhishek and Pratap (2020) and Martins et al. (2020) papers, however not with tangible results. As the findings and recommendations in this study are purely theoretical in nature, as previously mentioned in the sensitivity discussion in the recommendation section.

Besides contributing to the Lean and VSM relevance and applicability to the warehousing context, this thesis supports the notion and shows that there are a lot of moving parts in a warehouse and that balancing configurational elements can be challenging. As mentioned by Kembro and Norrman (2020) and Kembro, Norrman and Eriksson (2018), it is important to understand the configurational goals of a warehouse before suggesting any changes, and that a top-down approach is important when making configurational changes, is aspects which this thesis contributes to. To avoid any recommendations leading to suboptimizations in a system, it is important to obtain a holistic view of the investigated system. This thesis additionally adds to this and confirms the by Chopra and Meindl (2007) and Hayes Wheelwright (1979) presented frameworks applicability for reviewing processes holistically in a warehousing context. Consistent with the purpose of this research, this study primarily strengthens and continues building onto pre-existing theory within the field of warehousing and adjacent topics.

7.3 Limitations

To the findings of this thesis study, it is necessary to reiterate what was mentioned in the methodology section about some of the drawbacks of the selected research structure and approach. It being a single case study significantly limits the generalizability of the conclusion made from the findings. Just a single case company was investigated, located in Sweden, and the perishables industry. Meaning that the findings are limited to that specific context and company, therefore restricting the generalizability of the results. To enhance the generalizability, multiple case studies investigating several companies through this same means could be performed. Data availability was also partly limited in the study, mainly the quantitative data, either due to lack thereof or restricted access. An example of lacking data was for the lines per order for the crates flow channel, where it did not specify the exact number of crates but instead just the number of “loads”, nor was the shipping departure data available, which instead meant having to use the drop-off at bay confirmation time to calculate the MTBD. Restricted access occurred when for instance investigating the complaints data in terms of the precise monetary values. Site availability was also partly limited in the study, due to the geographical distance and Covid-19 regulations. Observations would otherwise presumably have taken on a larger part of the empirical findings in the study. Another noteworthy aspect is that there is a single author for this thesis, meaning that a lot of the study is based on just one perspective. If the same study were to be conducted by two or more authors instead, perhaps some rationales and conclusions would take on different a form based on the increased nuance.

7.4 Future research

Future research of this thesis findings could be to investigate the finding’s generalizability by conducting a multiple case study. With this thesis’s main contribution to the theory being the applicability of Lean and the VSM approach to identify efficiency problems in a warehouse, uncovering if similar conclusions can be made in more cases would strengthen the findings. The suggested first step would be to investigate other subsidiaries within the same organization after similar findings then move on to another organization’s warehouse in the same industry, subsequently investigating national or industry-wide to ensure a generalizable summation. In the immediate aftermath of this thesis study, future research could be to forge an implementation plan based on made recommendations and subsequently perform action research, to fully realize made suggestions. This would strengthen the validity of the findings and made recommendations.

At the case company warehouse, the focus lied on investigating the main material flow channels, an interesting future research area would be to investigate the immaterial flows in the warehouse. Make a more in-depth analysis of the flow of information, information systems, and modules used in the warehouse. Based on some of the findings, particularly from the interviews, the current planning structure is not the preferred choice for the case company warehouse. It is of growing interest at the case company to revise the current central planning structure. While it certainly presents many benefits in having more efficient large-scale planning and standards for all branches in the organization, it does occasionally create regional problems. No region is completely identical, an investigation about if having more regional planning could be more beneficial to help better orchestrate the workload at the subsidiaries could an interesting follow-up project.

Besides the planning process, inventory control is an area highlighted by the interviewees as questionable, with room for improvements. Future research could investigate the current inventory levels and set up an optimization or simulation model, to analyze the performance of the current configuration in relation to desired service levels and cost. Finally, since the mechanization and automation solutions are a prominent feature of the investigated warehouse, an area for future research could be investigating the implementation of more such solutions e.g., a fully automated picking process for fine picking using modern technology. In reviewing any additional automation solutions, it is important to keep in mind the overall strategic orientation of the organization and ensuring that thorough feasibility and risk analyses are made.

References

Abhishek, P.G. and Pratap, M. (2020). Achieving Lean Warehousing Through Value Stream Mapping. *South Asian Journal of Business & Management Cases*. 9(3), pp.387-401. doi: 10.1177/2277977920958551.

Abushaikha, I., Salhieh, L. and Towers, N. (2018). Improving distribution and business performance through lean warehousing. *International Journal of Retail & Distribution Management*. 46(8), pp.780-800. doi: 10.1108/IJRDM-03-2018-0059.

Antony, J., Snee, R. and Hoerl, R. (2017). Lean Six Sigma: yesterday, today and tomorrow. *International Journal of Quality & Reliability Management*. 34(7), pp.1073-1093. doi: 10.1108/IJQRM-03-2016-0035.

Arla Foods. (2020). *Bondeägda*. https://www.arla.se/om-arla/bondeagda/ [Accessed 26 January 2021].

Arla Foods. (2020a). *Arlas historia*. https://www.arla.se/om-arla/arlas-historia/ [Accessed 26 January 2021].

Arla Foods. (2020b). *Koncernen Arla*. https://www.arla.se/om-arla/koncernen/ [Accessed 26 January 2021].

Arla Foods. (2020c). *Våra mejerier*. https://www.arla.se/om-arla/mejerier/ [Accessed 26 January 2021].

Arla Foods. (2020d). *Jönköping mejeri*. https://www.arla.se/om-arla/mejerier/jonkoping-mejeri/ [Accessed 26 January 2021].

Arnheiter, E.D. and Maleyeff, J. (2005). The integration of lean management and Six Sigma. *The TQM Magazine*. 17(1), pp.5-18. doi: 10.1108/09544780510573020.

Asmae, M., Abdelali, E., Youssef, S. and Brahim, H. (2019). The utility of Lean Six Sigma(LSS) in the Supply Chain agro-industry. *2019 International Colloquium on Logistics and Supply Chain Management (LOGISTIQUA)*, Montreuil – Paris, France, 2019. pp.1-7. doi: 10.1109/LOGISTIQUA.2019.8907300.

ASQ. (2021). *What are the five S's (5S) of lean*. https://asq.org/quality-resources/lean/five-s-tutorial [Accessed 7 June 2021].

ASQ. (2021a). *Quality glossary – K*. https://asq.org/quality-resources/quality-glossary/k [Accessed 8 June 2021].

ASQ. (2021b). *What is the Plan-Do-Check-Act (PDCA) cycle?*. https://asq.org/quality-resources/pdca-cycle [Accessed 8 June 2021].

ASQ. (2021c). *ASQ Quality Tools – 5 Whys*. https://asq.org/training/asq-quality-tools---5-whys-5wasq [Accessed 10 June 2021].

ASQ. (2021d). *What is Mistake Proofing?*. https://asq.org/quality-resources/mistake-proofing [Accessed 10 June 2021].

ASQ (2021e). *What is a Spaghetti Diagram?*. https://asq.org/quality-resources/spaghetti-diagram [Accessed 11 June 2021].

ASQ. (2021f). *What is Value Stream Mapping (VSM)?*. https://asq.org/quality-resources/lean/value-stream-mapping [Accessed 2 Mars 2021].

Azevedo, J., Sá, J.C., Ferreira, L.P., Santos, G., Cruz, F.M., Jimenez, G. and Silva, F.J.G. (2019). Improvement of Production Line in the Automotive Industry Through Lean Philosophy. *Procedia Manufacturing*. 41, pp.1023-1030. doi: 10.1016/j.promfg.2019.10.029.

Baker, P. and Canessa, M. (2009). Warehouse design: A structured approach. *European Journal of Operational Research*. 193(2), pp.425-436. doi: 10.1016/j.ejor.2007.11.045.

Bartholdi, J.J. and Hackman, S.T. (2019). *Warehouse & distribution science*. Release 0.98.1. Atlanta, GA: The Supply Chain and Logistics Institute, Georgia Institute of Technology.

Bartholomew, D. (2008). *Putting Lean Principles in the Warehouse*. Lean Enterprise Institute. https://www.lean.org/common/display/?o=813 [Accessed 22 January 2021].

Bellgran, M. and Säfsten, K. (2010). Production Development: Design and Operation of Production Systems. 1st ed. London: Springer.

Benbasat, I., Goldstein, D.K. and Mead, M. (1987). The Case Research Strategy in Studies of Information Systems. *MIS Quarterly*. 11(3), pp.369-386. doi: 10.2307/248684.

Bhat, S., Gijo, E.V. and Jnanesh, N.A. (2016). Productivity and performance improvement in the medical records department of a hospital: An application of Lean Six Sigma. *International Journal of Productivity and Performance Management*. 65(1), pp.98-125. doi: 10.1108/IJPPM-04-2014-0063.

Brkic, V.S. and Tomic, B. (2016). Employees factors importance in Lean Six Sigma concept. *The TQM Journal*. 28(5), pp.774-785. doi: 10.1108/TQM-10-2015-0131.

Brunt, D. (2000). From Current State to Future State: Mapping the Steel to Component Supply Chain. *International Journal of Logistics: Research & Applications*. 3(3), pp.259-271. doi: 10.1080/713682765.

Chaudhuri, A., Dukovska-Popovska, I., Subramanian, N., Chan, H.K. and Bai, R. (2018). Decision-making in cold chain logistics using data analytics: a literature review. *The International Journal of Logistics Management*. 29(3), pp.839-861. doi: 10.1108/IJLM-03-2017-0059.

Chopra, S. and Meindl, P. (2007). *Supply Chain Management: Strategy, Planning & Operations*. 3rd ed. Harlow Essex: Pearson Education.

Childerhouse, P. and Towill, D.R. (2003). Simplified material flow holds the key to supply chain integration. *Omega*. 31(1), pp.17-27. doi: 10.1016/S0305-0483(02)00062-2.

Custodio, L. and Machado, R. (2020). Flexible automated warehouse: a literature review and an innovative framework. *International Journal of Advanced Manufacturing Technology*. 106(1/2), pp.533-558. doi: 10.1007/s00170-019-04588-z.

de Koster, R., Le-Duc, T. and Roodbergen, K.J. (2007). Design and control of warehouse order picking: A literature review. *European Journal of Operational Research*. 182(2), pp.481-501. doi: 10.1016/j.ejor.2006.07.009.

de Leeuw, S. and Wiers, V.C.S. (2015). Warehouse manpower planning strategies in times of financial crisis: Evidence from logistics service providers and retailers in the Netherlands. *Production Planning and Control*. 26(4), pp.328-337. doi: 10.1080/09537287.2014.904531.

Dervitsiotis, K.N. (1998). The challenge of managing organizational change: Exploring the relationship of re-engineering, developing learning organizations and total quality management. *Total Quality Management*. 9(1), pp.109-122. doi: 10.1080/0954412989306.

Dewi, D.S. and Septiana, T. (2015). Workforce scheduling considering physical and mental workload: A case study of domestic freight forwarding. *Procedia Manufacturing*. 4, pp.445-453. doi: 10.1016/j.promfg.2015.11.061.

Dresch, A., Veit, D.R., Lima, P.N., Lacerda, D.P. and Collatto, D.C. (2019). Inducing Brazilian manufacturing SMEs productivity with Lean tools. *International Journal of Productivity and Performance Management*. 68(1), pp.69-87. doi: 10.1108/IJPPM-10-2017-0248.

Durach, C.F., Kembro, J. and Wieland, A. (2017). A New Paradigm for Systematic Literature Reviews in Supply Chain Management. *Journal of Supply Chain Management*. 53(4), pp.67-85. doi: 10.1111/jscm.12145.

Eisenhardt, K.M. and Graebner, M.E. (2007). Theory Building from Cases: Opportunities and Challenges. *Academy of Management Journal*. 50(1), pp.25-32. doi: 10.5465/AMJ.2007.24160888.

EL-Khalil, R., Leffakis, Z.M. and Hong, P.C. (2020). Impact of improvement tools on standardization and stability goal practices: An empirical examination of US automotive firms. *Journal of Manufacturing Technology Management*. 31(4), pp.705-723. doi: 10.1108/JMTM-08-2019-0289.

Eriksson, E., Norrman, A. and Kembro, J. (2019). Contextual adaptation of omni-channel grocery retailers' online fulfilment centres. *International Journal of Retail & Distribution Management*. 47(12), pp.1232-1250. doi: 10.1108/IJRDM-08-2018-0182.

Faber, N., de Koster, M.B.M. and Smidts, A. (2013). Organizing warehouse management. *International Journal of Operations & Production Management*. 33(9), pp.1230-1256. doi: 10.1108/IJOPM-12-2011-0471.

Fisher, M. (2007). Strengthening the Empirical Base of Operations Management. *Manufacturing & Service Operations Management*. 9(4), pp.368-382. doi: 10.1287/msom.1070.0168.

Fisher, M.L. (1997). What Is the Right Supply Chain for Your Product?. *Harvard Business Review*. 75(2), pp.105-116.

Forza, C. (2002). Survey research in operations management: a process-based perspective. *International Journal of Operations & Production Management*. 22(2), pp.152-194. doi: 10.1108/01443570210414310.

Gu, J., Goetschalckx, M. and McGinnis, L.F. (2007). Research on warehouse operation: A comprehensive review. *European Journal of Operational Research*. 177(1), pp.1-21. doi: 10.1016/j.ejor.2006.02.025.

Gu, J., Goetschalckx, M. and McGinnis, L.F. (2010). Research on warehouse design and performance evaluation: A comprehensive review. *European Journal of Operational Research*. 203(3), pp.539-549. doi: 10.1016/j.ejor.2009.07.031.

Gunasekaran, A., Marri, H.B. and Menci, F. (1999). Improving the effectiveness of warehousing operations: a case study. *Industrial Management & Data Systems*. 99(8), pp.328-339. doi: 10.1108/02635579910291975.

Gutierrez-Gutierrez, L., de Leeuw, S. and Dubbers, R. (2016). Logistics services and Lean Six Sigma implementation: a case study. *International Journal of Lean Six Sigma*. 7(3), pp.324-342. doi: 10.1108/IJLSS-05-2015-0019.

Göransson, M., Nilsson, F. and Jevinger, Å. (2018). Temperature performance and food shelf-life accuracy in cold food supply chains – Insights from multiple field studies. *Food Control*. 86, pp.332-341. doi: 10.1016/j.foodcont.2017.10.029.

Hallgren, M. and Olhager, J. (2009). Lean and agile manufacturing: external and internal drivers and performance outcomes. *International Journal of Operations & Production Management*. 29(10), pp.976-999. doi: 10.1108/01443570910993456.

Hayes, R.H. and Wheelwright, S.C. (1979). Link manufacturing process and product life cycles. *Harvard Business Review*. 57(1), pp.133-140.

Hines, P. and Rich, N. (1997). The seven value stream mapping tools. *International Journal of Operations & Production Management*. 17(1), pp.46-64. doi: 10.1108/01443579710157989.

Hines, P., Holweg, M. and Rich, N. (2004). Learning to evolve: A review of contemporary lean thinking. *International Journal of Operations & Production Management*. 24(10), pp.994-1011. doi: 10.1108/01443570410558049.

Hu, K. and Chang, T. (2010). An innovative automated storage and retrieval system for B2C e-commerce logistics. *International Journal of Advanced Manufacturing Technology*. 48, pp.297-305. doi: 10.1007/s00170-009-2292-4.

Hübner, A., Holzapfel, A. and Kuhn, H. (2016). Distribution systems in omni-channel retailing. *Business Research*. 9(2), pp.255-296. doi: 10.1007/s40685-016-0034-7.

Ishikawa, K. (1985). *What is Total Quality Control? The Japanese way*. 1st ed. Englewood Cliffs, New Jersey: Prentice-Hall.

Jain, B., Adil, G.K. and Ananthakumar, U. (2013). An instrument to measure factors of strategic manufacturing effectiveness based on Hayes and Wheelwright's model. *Journal of Manufacturing Technology Management*. 24(6), pp.812-829. doi: 10.1108/JMTM-11-2011-0102.

Kembro, J. and Norrman, A. (2019). Exploring trends, implications and challenges for logistics information systems in omni-channels: Swedish retailers' perception. *International Journal of Retail & Distribution Management*. 47(4), pp.384-411. doi: 10.1108/IJRDM-07-2017-0141.

Kembro, J.H. and Norrman, A. (2020). Warehouse configuration in omni-channel retailing: a multiple case study. *International Journal of Physical Distribution & Logistics Management*. 50(5), pp.509-533. doi: 10.1108/IJPDLM-01-2019-0034.

Kembro, J.H. and Norrman, A. (2021). Which future path to pick? A contingency approach to omnichannel warehouse configuration. *International Journal of Physical Distribution & Logistics Management*. 51(1), pp.48-75. doi: 10.1108/IJPDLM-08-2019-0264.

Kembro, J.H., Danielsson, V. and Smajli, G. (2017). Network video technology: Exploring an innovative approach to improving warehouse operations. *International Journal of Physical Distribution & Logistics Management*. 47(7), pp.623-645. doi: 10.1108/IJPDLM-02-2017-0112.

Kembro, J.H., Norrman, A. and Eriksson, E. (2018). Adapting warehouse operations and design to omni-channel logistics: A literature review and research agenda. *International Journal of Physical Distribution & Logistics Management*. 48(9), pp.890-912. doi: 10.1108/IJPDLM-01-2017-0052.

Knapp, S. (2015). Lean Six Sigma implementation and organizational culture. *International Journal of Health Care Quality Assurance*. 28(8), pp.855-863. doi: 10.1108/IJHCQA-06-2015-0079.

Knol, W.H., Slomp, J., Schouteten, R.L.J. and Lauche, K. (2018). Implementing lean practices in manufacturing SMEs: testing ‘critical success factors’ using Necessary Condition Analysis. *International Journal of Production Research*. 56(11), pp.3955-3973. doi: 10.1080/00207543.2017.1419583.

Leidecker, J.K. and Bruno, A.V. (1984). Identifying and Using Critical Success Factors. *Long Range Planning*. 17(1), pp.23-32. doi: 10.1016/0024-6301(84)90163-8.

Leksic, I., Stefanic, N. and Veza, I. (2020). The impact of using lean manufacturing tools on waste reduction. *Advances in Production Engineering & Management*. 15(1), pp.81-92. doi: 10.14743/apem2020.1.351.

Lim, M.K., Bahr, W. and Leung, S.C.H. (2013). RFID in the warehouse: A literature analysis (1995-2010) of its applications, benefits, challenges and future trends. *International Journal of Production Economics*. 145(1), pp.409-430. doi: 10.1016/j.ijpe.2013.05.006.

Lumsden, K. (2007). *Fundamentals of Logistics*. Compendium, Division of Logistics and Transportation, Chalmers University of Technology.

Malhotra, M.K. and Grover, V. (1998). An assessment of survey research in POM: from constructs to theory. *Journal of Operations Management*. 16(4), pp.407-425. doi: 10.1016/s0272-6963(98)00021-7.

Martins, R., Pereira, M.T., Ferreira, L.P., Sá, J.C. and Silva, F.J.G. (2020). Warehouse operations logistics improvement in a cork stopper factory. *Procedia Manufacturing*. 51, pp.1723-1729. doi: 10.1016/j.promfg.2020.10.240.

Mattsson, S.-A. and Jonsson, P. (2013). *Material- och produktionsstyrning*. 1st ed. Lund: Studentlitteratur AB.

Mattsson, S.-A. (2012). *Logistik i försörjningskedjor*. 2nd ed. Lund: Studentlitteratur AB.

Melton, T. (2005). The Benefits of Lean Manufacturing: What Lean Thinking has to Offer the Process Industries. *Chemical Engineering Research and Design*. 83(6), pp.662-673. doi: 10.1205/cherd.04351.

Meredith, J. (1998). Building operations management theory through case and field research. *Journal of Operations Management*. 16(4), pp.441-454. doi: 10.1016/s0272-6963(98)00023-0.

Nepal, B.P., Yadav, O.P. and Solanki, R. (2011). Improving the NPD Process by Applying Lean Principles: A Case Study. *Engineering Management Journal*. 23(1), pp.52-68. doi: 10.1080/10429247.2011.11431886.

Näslund, D. (2013). Lean and six sigma – critical success factors revisited. *International Journal of Quality and Service Sciences*. 5(1), pp.86-100. doi: 10.1108/17566691311316266.

Okeudo, G.N. and Uche, C.D. (2013). Correlational Analysis of Distribution Cost and Freight Characteristics of Manufactured Goods (Case Study of Unilever Nigeria Plc). *Journal of Logistics Management*. 2(1), pp.26-34.

Patel, R. and Davidson, B. (2011). Forskningsmetodikens grunder: att planera, genomföra och rapportera en undersökning. 4th ed. Lund: Studentlitteratur AB.

Pepper, M.P.J. and Spedding, T.A. (2010). The evolution of lean Six Sigma. *International Journal of Quality & Reliability Management*. 27(2), pp.138-155. doi: 10.1108/02656711011014276.

Popović, V., Kilibarda, M., Andrejić, M., Jereb, B. and Dragan, D. (2021). A New Sustainable Warehouse Management Approach for Workforce and Activities Scheduling. *Sustainability*. 13(4). doi.org/10.3390/su13042021.

Ramer, S.L. (2005). Site-ation pearl growing: methods and librarianship history and theory. *Journal of the Medical Library Association*. 93(3), pp.397-400.

Rizzi, A. and Zamboni, R. (1999). Efficiency improvement in manual warehouses through ERP systems implementation and redesign of the logistics processes. *Logistics Information Management*. 12(5), pp.367-377. doi: 10.1108/09576059910295805.

Rouwenhorst, B., Reuter, B., Stockrahm, V., van Houtum, G.J., Mantel, R.J. and Zijm, W.H.M. (2000). Warehouse design and control: Framework and literature review. *European Journal of Operational Research*. 122(3), pp.515-533. doi: 10.1016/S0377-2217(99)00020-X.

Saunders, M., Lewis, P. and Thornhill, A. (2009). *Research methods for business students*. 5th ed. Harlow: Pearson Education Ltd.

Simonsson, P., Björnfot, A., Erikshammar, J. and Olofsson, T. (2012). 'Learning to see' the Effects of Improved Workflow in Civil Engineering Projects. *Lean Construction Journal*. pp.35-48.

Staudt, F.H., Alpan, G., Di Mascolo, M. and Rodriguez, C.M.T. (2015). Warehouse performance measurement: a literature review. *International Journal of Production Research*. 53(18), pp.5524-5544. doi: 10.1080/00207543.2015.1030466.

Stuart, I., McCutcheon, D., Handfield, R., McLachlin, R. and Samson, D. (2002). Effective case research in operations management: a process perspective. *Journal of Operations Management*. 20(5), pp.419-433. doi: 10.1016/S0272-6963(02)00022-0.

Tortorella, G.L., Narayanamurthy, G. and Thurer, M. (2021). Identifying pathways to a high-performing lean automation implementation: An empirical study in the manufacturing industry. *International Journal of Production Economics*. 231. doi: 10.1016/j.ijpe.2020.107918.

van den Berg, J.P. and Zijm, W.H.M. (1999). Models for warehouse management: Classification and examples. *International Journal of Production Economics*. 59(1-3), pp.519-528. doi: 10.1016/S0925-5273(98)00114-5.

Villareal, B., Garza, F., Rosas, I. and Garcia, D. (2012). An Introduction to Distribution Operational Efficiency. *International Journal of Industrial Engineering*. 19(7), pp.278-288.

Voss, C., Tsikriktsis, N. and Frohlich, M. (2002). Case research in operations management. *International Journal of Operations & Production Management*. 22(2), pp.195-219. doi: 10.1108/01443570210414329.

Yilmaz, O.F., Ozcelik, G. and Yeni, F.B. (2020). Lean holistic fuzzy methodology employing cross-functional worker teams for new product development projects: A real case study from high-tech industry. *European Journal of Operational Research*. 282(3), pp.989-1010. doi: 10.1016/j.ejor.2019.09.048.

Appendix A – Interview guides

Interview guide A

Purpose of interview

The purpose is to better understand how the warehouse operates and is configured, by gaining insights about the processes and the daily operations. Similar, or same guide is used when conducting the interview for each informant, the Senior Warehouse Manager, Warehouse Manager, and Team Leader. If it is ok with the interviewee, the interview will be recorded for later transcript, alternatively notes will be taken during.

About the interviewee

Who are you and can you describe your role at the company?
What are your daily operations, what do you do during the day?
How long have you worked at this position and at this company?
What are your previous experiences?

About the warehouse

What purpose does the warehouse serve for the company?
What customers does the warehouse serve?
Who are the suppliers?
What KPIs does the warehouse adhere to and why? Do you find these agreeable?
How does the current layout look?
What are the main material flow channels?
What reasoning lies behind the current layout and configuration of the warehouse?
What equipment is used? Trucks/Shelves/…
What issues do you see with the configuration? Long distances/congestion/needless movement of goods/double handling/…
Anything you want to change?
Anything you like to promote about the configuration?
Labor management, what shifts are run and sequencing of personnel?
Demand characteristics, is there any seasonality?

Manufacturing

Can you describe the manufacturing processes?
What do you manufacture here/what do you procure?
How long is the manufacturing process? Lead times/Setup times
Why does it look the way it does?
Anything that you want to change about the manufacturing?

Inbound

How are the inbound processes configured?
How is the goods received and from where?
Are the goods scanned upon arrival?
What SKUs does the goods arrive in? Is there any repackaging required?

How does the put-away work?
How do you distribute the goods and any policies you adhere to (FIFO)?
What are the storage policies?
Does the process differ for different SKUs? Where do the different SKUs go?

Does any SKUs require special handling?
Why does it look the way it does, and do you see any issues with it?

Outbound

How does the picking process work? Picking routes/Picking lists/Picking policies/Order generation, when and how do the pickers get the lists/Where are the orders dropped off/…
Manual or automated processes (and to which extents)?
Does the process differ for different SKUs or products?

Is there any packing process before loading?
How and when are products loaded onto trucks/How does the loading process work?
Does it differ for different SKUs?
Why does it look like this?
Does something need changing?

Returns

Do you handle any returns? How?
Anything that needs improvements?

Information systems

What information systems are used? ERP/WMS/...
Are there any compatibility issues?
What modules do you utilize, any you want to add or find needless?
How are orders processed?
How do you work with operations planning, inventory management, and forecasting?

Automation

How do you work with automation?
Any challenges?
Do you want to see more automated solutions applied at the warehouse? What in that case and why?

Lean

Do you work with continuous improvements?
Which Lean tools or approaches do you apply, and which would you like to see more of/add?
Do you follow the Lean principles?
Is it important and applied at the entire organization, why/why not?

Interview guide B

Purpose of interview

The purpose is to gain an understanding about the three main material flow channels, to help map out the current state of the warehouse. Knowing how the flows are configured and their main processes is the primary objective. The Warehouse Manager and Team Leaders are the targeted interviewees. If agreeable with the interviewees the interviews will be recorded for later transcript.

Fine picking

What SKUs or items moves through this flow?
In relation to the physical layout, what does the material flow movement look like?
How does the unloading work?
How does the put-away process work? What rule does the put-away algorithm follow?
How are the SKUs stored in the system? Main storage and intermediaries. How are inventory levels managed?
How does the picking process work? Are there any picking policies or picking routes for pickers to adhere to (Picking lists)?
What happens after the orders are picked? Where are they transported?
How are the order-lists generated?
What handling equipment is used in the flow?
Are there any quality controls? Where and why?
What role does automation play in the flow channel, what automation solutions are used?
What information system(s) is used?
How many FTEs are in the flow?
How does the workforce planning work?
What shift types are there?
Are any Lean approaches or tools used in the flow?

Tets

What SKUs or items moves through this flow?
In relation to the physical layout, what does the material flow movement look like?
How does the unloading work?
How does the put-away process work?
How are the SKUs stored in the system? Main storage and intermediaries. How are inventory levels managed?
How does the picking process work? Are there any picking policies or picking routes for pickers to adhere to (Picking lists)?
What happens after the orders are picked? Where are they transported?
What handling equipment is used in the flow?
Are there any quality controls? Where and why?
What role does automation play in the flow channel, what automation solutions are used?
What information system(s) is used?
How many FTEs are in the flow?
How does the workforce planning work?
What shift types are there?
Are any Lean approaches or tools used in the flow?

Crates

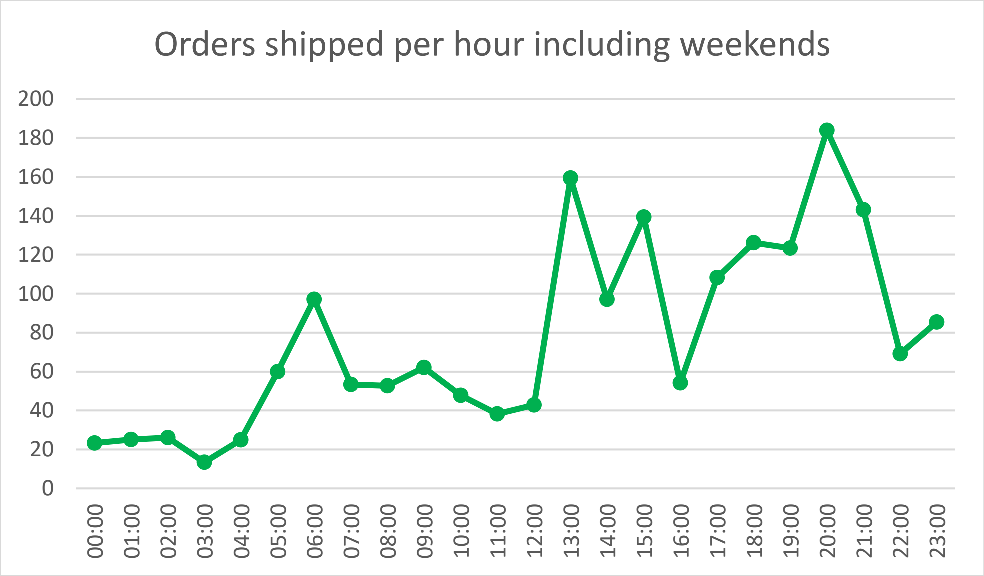
What SKUs or items moves through this flow?
In relation to the physical layout, what does the material flow movement look like?
How does the unloading work?
How does the put-away process work?
How are the SKUs stored in the system? Main storage and intermediaries. How are inventory levels managed?
How does the picking process work? Are there any picking policies or picking routes for pickers to adhere to (Picking lists)?
What happens after the orders are picked? Where are they transported?
What handling equipment is used in the flow?
Are there any quality controls? Where and why?
What role does automation play in the flow channel, what automation solutions are used?
What information system(s) is used?
How many FTEs are in the flow?
How does the workforce planning work?
What shift types are there?
Are any Lean approaches or tools used in the flow?

Other

Are there any other material flow channels at the warehouse?
If so, how is the flow related to the other flow channels (location, technology, processes), how are they configured, and what SKUs are moved through it?

Appendix B – Supplementary orders shipped per hour graphs

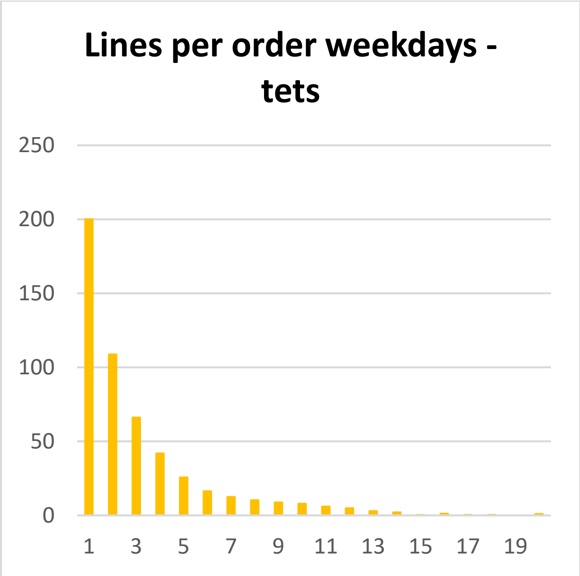
Total average

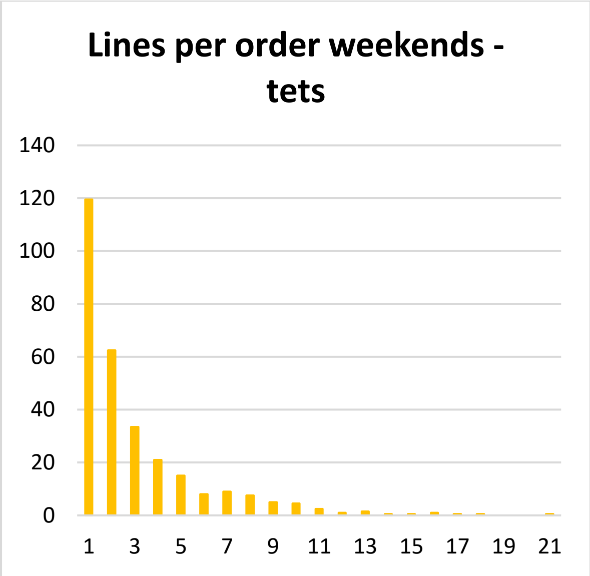


Saturday and Sunday averages

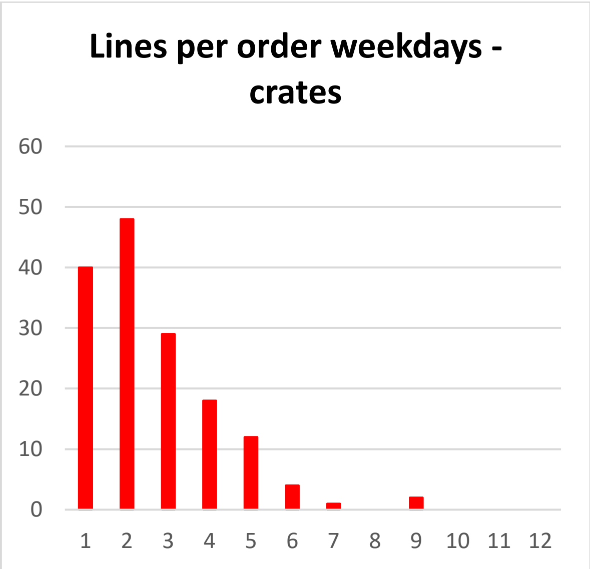
Appendix C – Supplementary lines per order graphs

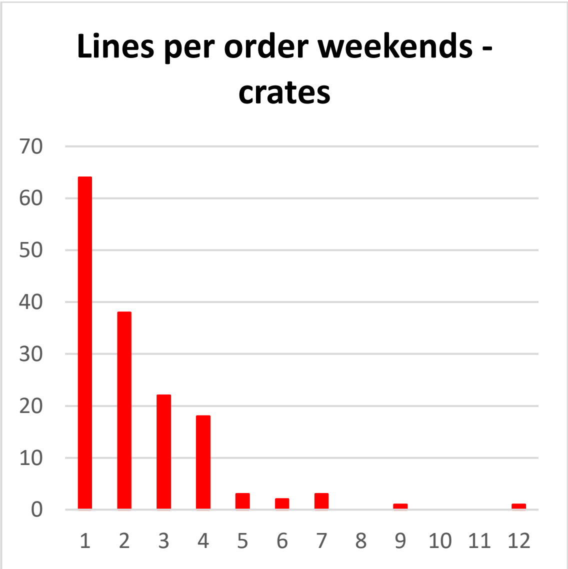
Tets





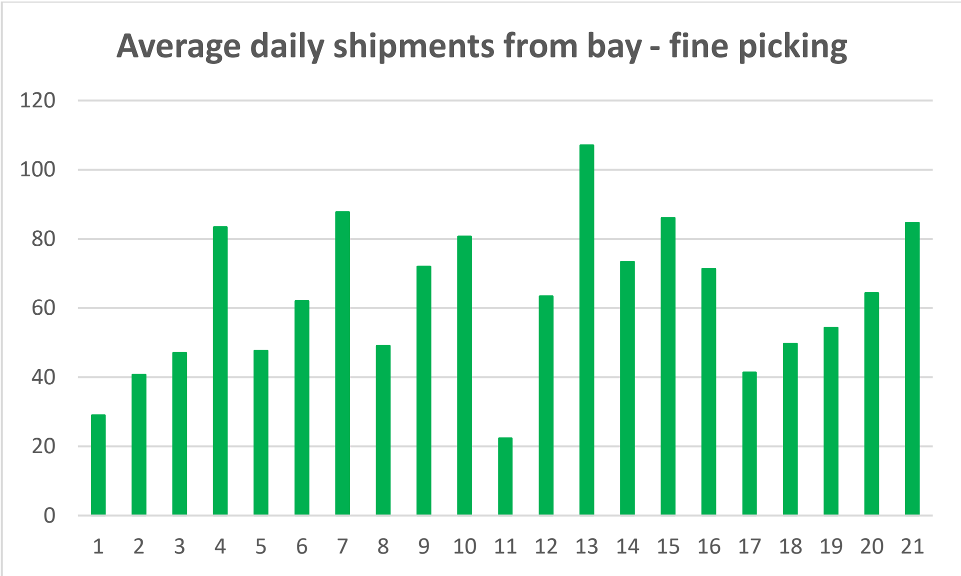
Crates



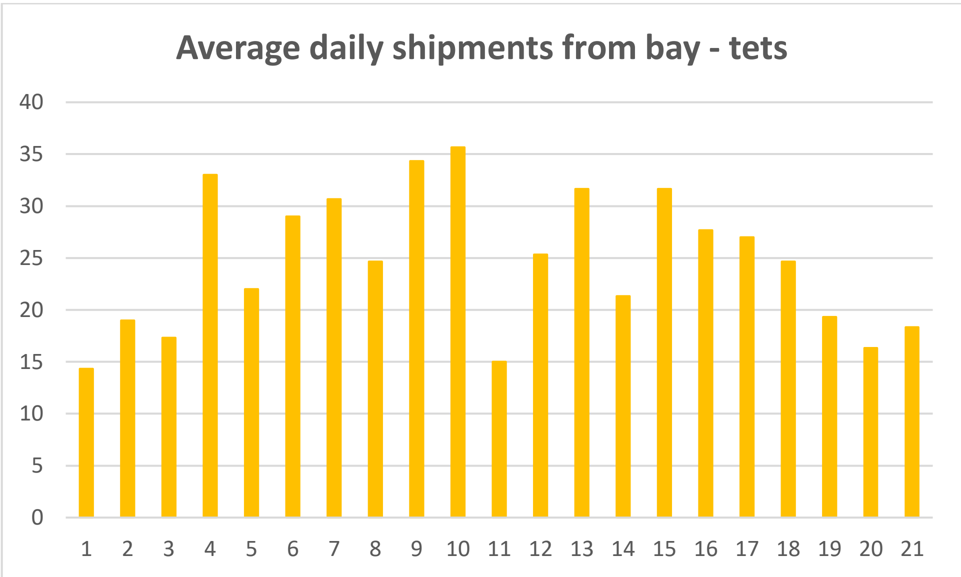


Appendix D – Average amount of orders shipped from bay

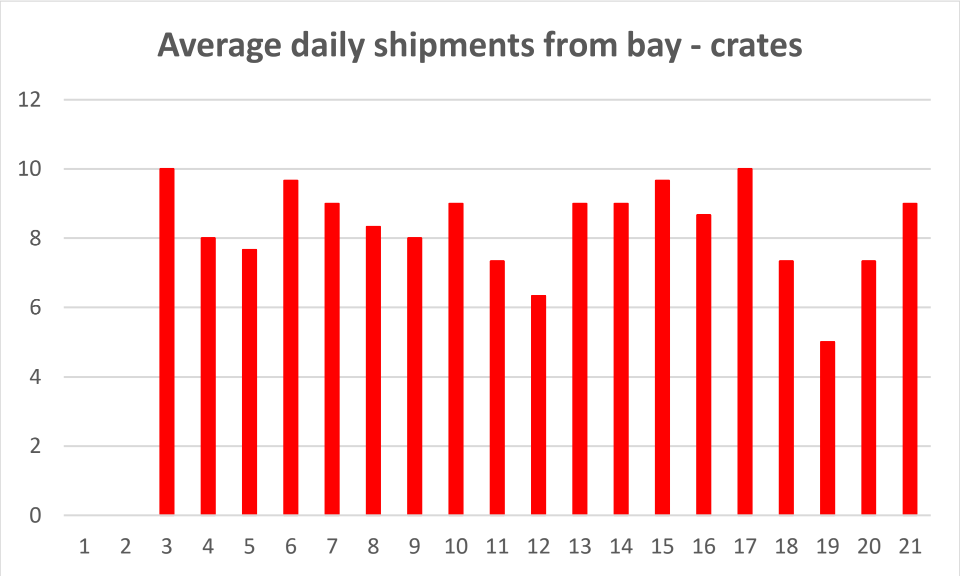
Fine picking



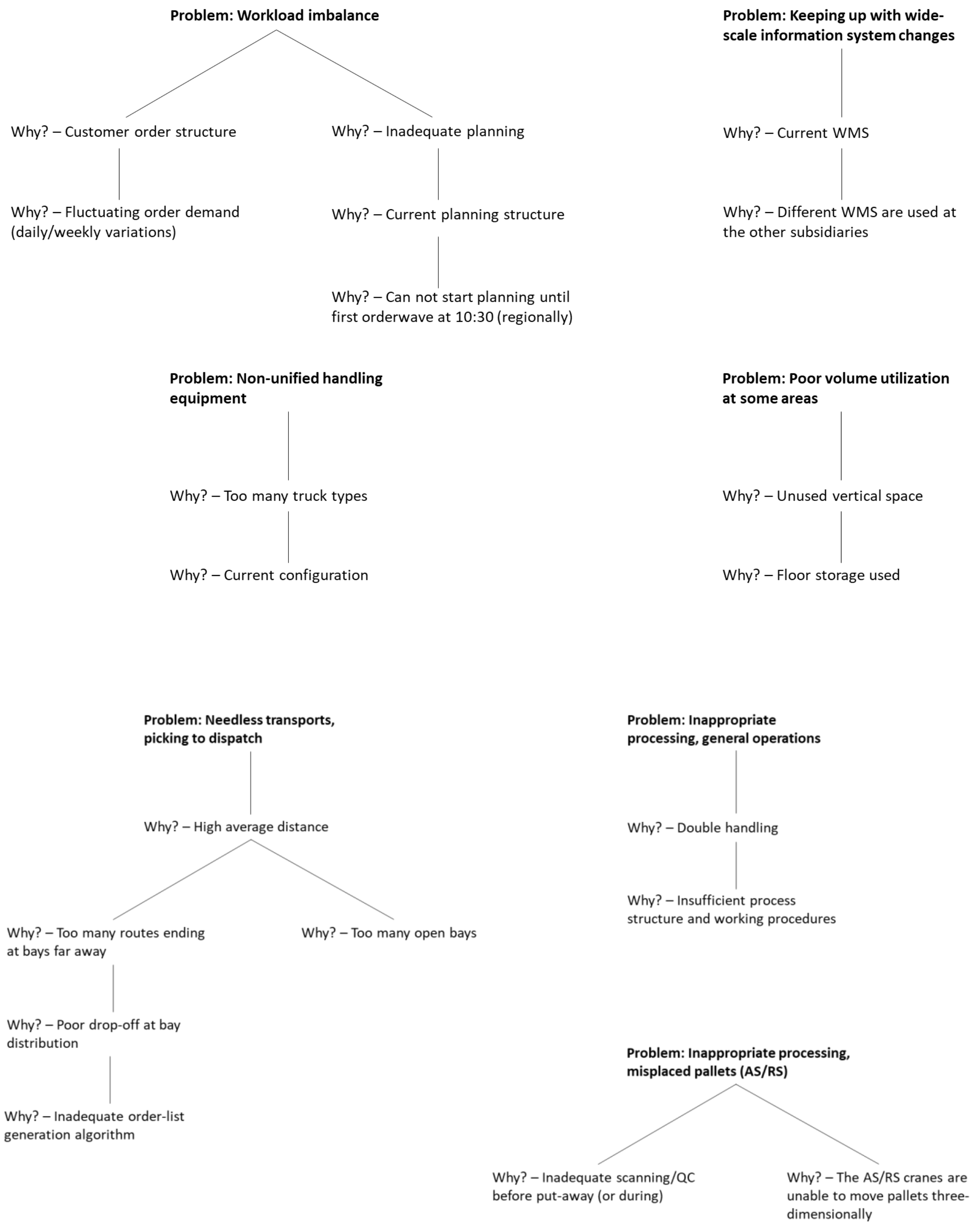
Tets



Crates


Average daily shipments from bay - crates
12
10
8
6
4
2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

Appendix E – 5 Why analysis



Problem: Redundant stock, in general too high inventory levels – expiration dates (spillage)

- Why? – Push flow in and pull flow out

Problem: Redundant stock, intermediate stock points (KPV-square)

- Why? – Additional touch point before drop-off at bays 1-8 (fine picking)
  - Why? – Congestion, safety

Problem: Redundant stock, intermediate stock points (inbound → put-away) (picking → outbound)

- Why? – Touch points (waste)
  - Why? – Non-continuous flow
    - Why? – No automation solutions

Problem: Redundant stock, intermediate stock point (in-house production facility → carousel)

- Why? – Waiting time (before being picked up
  - Why? – Two independent systems
    - Why? – Poor synchronization

Problem: Defects (fine picking)

- Why? – Customer complaints (many)
  - Why? – Various reasons, some caused by the distribution unit (trucks), wrongly picked item, expired products, misplaced customer orders, etc.
    - Why? – Inadequate quality control or operating procedures

Problem: Defects (tets)

- Why? – High backorder cost
  - Why? – SKU characteristics
- Why? – Wrongly picked item
  - Why? – Current picking process
    - Why? – Inadequate picking technology

Problem: Defects (crates)

- Why? – Spillage
  - Why? – Crates tips over
    - Why? – Load carrier design

Problem: Picking operation (fine picking)

- Why? – Time consuming
  - Why? – Transportation to picking locations
    - Why? – Order characteristics
    - Why? – Layout