IMPROVING WAREHOUSE PICKING PERFORMANCE BY USING CONTEXTUAL FACTORS AND LEAN PRACTICES

A Design Science Study at Tetra Pak

Master Thesis for M.Sc. in Mechanical Engineering

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ABSTRACT

Title: Improving Warehouse Picking Performance by Using Contextual Factors and Lean Practices: A Design Science Study at Tetra Pak

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Problem Description: As warehouses play an important role in the supply chain and are vital for the success of a company, it is important that they operate efficiently. Thus, Tetra Pak wants to increase their picking efficiency for their production warehouse by identifying and solving bottlenecks and wastes that decreases the performance.

Purpose: The purpose of this thesis is to develop a solution for how to increase warehouse picking efficiency by identifying and solving material-flow bottlenecks and wastes related to the picking process.

Objectives: Two research objectives were formulated to fulfil the purpose of the thesis. The first one is to develop an artifact based on contextual factors and lean practices to improve warehouse picking performance. The second objective is to test and evaluate the artifact by applying it to the Tetra Pak production warehouse.

Methodology: The study had a design science research strategy as it aimed to develop a solution. The first step was to do a literature review based on prior theories connected to warehousing, lean practices, and contextual factors, and create the artifact that can be used to increase picking performance. This artifact is then tested and evaluated by conducting a case study at the production warehouse at Tetra Pak. Data related to the picking performance was collected through observations, interviews, documents, and system data. The collected data was analysed with the help of pattern matching and the artifact. Lean practices helped locating bottlenecks and wastes, and the contextual factors helped designing suitable configurations.

Findings: Three potential bottlenecks were identified, along with their wastes and contextual factors with the help of the artifact. The bottlenecks were space utilization, pallet picking process, and the lift put-away and picking process. The empirical findings, prior theory, wastes, and contextual factors were used to formulate 12 general propositions on how to improve picking efficiency in certain contexts. The practical implications for the case company were that that they should increase collaboration and maintenance to improve space utilization, use a new zone configuration to remove wastes at the lift and pallet processes, and use batch picking to increase the performance of the lift and pallet picking.

Conclusion: This thesis involved the creation and validation of an artifact for increasing warehouse picking efficiency by identifying and solving material-flow bottlenecks and wastes related to the picking process. The artifact was found useful as it guided the data that was needed to be collected, as well as the analysis of it. The lean practices helped to locate the bottlenecks and waste, while the contextual factors helped to formulate better configurations that reduce wastes and increase the picking efficiency. The artifact was found useful and flexible as it had a systematic approach and was based on well-grounded and comprehensive theories. Since the artifact helped to formulate 12 propositions to improve the picking performance of the case company by targeting the bottlenecks and waste, it shows that it is an applicable framework. Thus, fulfilling the purpose of the thesis project.

Keywords: Warehousing, Lean, Picking, Performance, Production Warehouse, Contextual Factors, Value Stream Mapping, Bottlenecks, Wastes, Design Science

ABBREVIATIONS

AS/RS – Automated Storage and Retrieval System

BI – Business Intelligence

BPU – Branded Process Units

CAMO – Context – Agency – Mechanism – Outcome

ERP – Enterprise Resource Planning

FIFO – First In First Out

HP – High Pressure Pumps (Homogenizers)

HT – Heat Exchangers

LIFO – Last In First Out

KPI – Key Performance Indicator

RO – Research Objective

SKU – Stock Keeping Unit

SOP – Standard Operating Procedure

TO – Transfer Order

OCAM – Outcome – Context – Agency – Mechanism

VSM – Value Stream Mapping

QC – Quality Control

WMS – Warehouse Management System

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1 Background

Warehouses play an important role in the supply chain and can be regarded as having a vital role in the success of a company. Two main functions are to match supply with demand more efficiently and consolidate products, which are critical functions due to quick demand changes, reduced transportations costs and improved customer service (Bartholdi and Hackman, 2019; Gu, Goetschalckx and McGinnis, 2007). Kiefer and Novack (1999) highlight that a warehouse has a great impact on supply chain costs and service levels because of its critical intermediate role between supply chain members. Thus, it is crucial that warehouses are cost effective for businesses to succeed (Baker and Canessa, 2009). Furthermore, Rouwenhorst et al. (2000) stress that warehouses must manage the pressure from the increased demand of shorter response times and a larger product variety. To stay competitive, warehouses need to have efficient logistic operations, especially of picking where it is desirable to reduce the cost and increase the speed of order picking (Petersen, 1997; Rouwenhorst et al., 2000). This is because labour is often the most expensive part in warehousing and the main workload of a warehouse belongs to order-picking (Bartholdi and Hackman, 2019).

To improve the performance, it is important to consider the configurational elements of the warehouse and how they are designed to fit the contextual factors (Kembro and Norrman, 2020; Kembro, Norrman and Eriksson, 2018). Configurational elements include the design, equipment, and operations of the warehouse, and contextual factors means the operating environment that is hard to change. Donaldson (2001) highlight that if organizational decisions are aligned with the contextual factors, it will result in higher performance. A misalignment will instead result in loss of performance.

Another approach to improve the efficiency of warehouse operations, such as picking, is through continuous improvements of the material flow (De Koster, Le-Duc and Roodbergen, 2007; Gu, Goetschalckx and McGinnis, 2007). Bartholdi and Hackman (2019) highlight that it is necessary for warehouses to have smooth flows of goods, where starts and stops are avoided, and bottlenecks should be identified and targeted. However, to continuously improve the efficiency and effectiveness of complex warehouses is a difficult task and many errors can occur throughout the warehouse process (De Koster, Le-Duc and Roodbergen, 2007; Faber, de Koster and Smidts, 2013). Thus, a systematic approach is needed. Lean manufacturing is the most common approach for industrial continuous improvement and the principles can be applied to warehousing (Dotoli et al., 2013). According to Narasimhan, Swink and Kim (2006), the lean philosophy is about eliminating the waste that comes from unnecessary operations, inefficient operations, or excessive buffering in operations. Waste refers to the non-value adding activities, which means activities and materials that are not necessary to perform a certain process (Abushaikha, Salhieh and Towers, 2018).

Lean in a warehousing context starts with Value Stream Mapping (VSM), a simple and effective approach that can improve the material flow and warehouse operations by eliminating waste (Baby, Prasanth and Jebadurai, 2018; Dotoli et al., 2013; Garcia, 2003). It involves mapping out the material and information flow in a process to identify and manage inefficiencies and bottlenecks (Nandakumar, Saleeshya & Harikumar, 2020). Dharmapriya and Kulatunga (2011) stress that there are many non-value adding activities involved in warehouse operations such as picking, which results in high costs, and VSM is a useful tool for handling that matter. Abushaikha, Salhieh and Towers (2018) has shown with their study that warehouse waste reduction levels have a positive effect on warehouse operational performance and distribution performance. However, research on lean principles such as VSM in a warehousing context is still scarce (Abushaikha, Salhieh and Towers, 2018; Bartholomew, 2008; Dotoli et al, 2012). Yet, warehouses must adopt lean principles to become more efficient (Dotoli et al., 2013). Furthermore, bottlenecks are closely linked to VSM, as both are linked to the material flow. Like VSM, bottleneck management in a warehousing context is also scarce in the literature, even though it has been explored in other fields such as manufacturing and assembly (Brazhkin, 2014; Hinckeldeyn et al., 2014). Hinckeldeyn et al. (2014) highlight that bottleneck management is not limited to manufacturing and that other areas can benefit from it as well.

In conclusion, there seems to be a gap in the literature when it comes to VSM and bottleneck management in a warehousing context. This is especially important to investigate when it comes to the picking process because it accounts for a major cost of a warehouse. Thus, this thesis project aims to fill this knowledge gap by conducting a design science study. This means to develop an artifact that can be used to improve the picking process of a warehouse by focusing on bottlenecks and waste, as well as the contextual factors and configurational elements as they are closely connected to performance. In a design science study, an artifact is the solution that does not exist yet, but what is intended to be designed through the study and it has the purpose to solve a problem (Romme and Dimov, 2021). The developed artifact in this study will be a theoretical framework, which will be tested and evaluated through a case study at a production warehouse.

1.2 Case Company

A company that has a business need of improving their picking process is Tetra Pak and it will act as the company where the artifact will be applied. Tetra Pak is a world leading business that provides complete solutions for the processing, packaging, and distribution of liquid food and beverages, including dairy products. For this thesis project, the focus will be on Tetra Pak Processing Equipment and their site in Lund, which deals with processing solutions and equipment for food and beverages. The produced machines are customized after the needs of the customer, meaning that orders are engineer-to-order, which influences the operations at the company. The machines are divided into three product categories: branded process units (BPU), homogenizers which are known as high pressure pumps (HP), and lastly heat exchangers (HT). This thesis will especially focus on their production warehouse, which receives, stores, and consolidates all different raw materials of the machines that are going to be produced. The production warehouse has two main areas where inventory is stored. One storage area is inside, and the other is outside. The storage area inside consists of two large rooms, which will be called the south warehouse and north warehouse. The storage locations that is outside is called the yard and it is just outside the south and north warehouse.

1.3 Problem Formulation

According to the warehouse managers, it is important for the production warehouse of the case company to maintain their internal service level. This is important because the production is dependent on the materials from the warehouse to produce the machines and follow the schedule. Thus, the warehouse needs to deliver the right components, in the right time, to the right place in the production facility. To achieve this, they aim to have a lean flow, which means that there should be a smooth, and continuous material flow through the warehouse. This means having efficient warehouse operations with no wastes, especially for the picking operation as the picking performance determines the service level towards the production.

Based on initial discussions with Tetra Pak, the warehouse struggles with delivering materials on time to the production and there are problems that limit the flow and hinder an efficient picking process, which affects the service level. Thus, Tetra Pak wants to get a picture of the material flow and the bottlenecks related to the picking process and how to manage them. The bottlenecks are of interest because the material flow is slow there, and they want to resolve the wastes connected to them to get the resources to work at maximum level and increase the number of picks per day. The research gap related to lean practices in a warehousing context also makes it relevant to study the material flow and the bottlenecks of the Tetra Pak picking process as it will provide additional knowledge to the topic. Also, as it is a production warehouse that handles SKUs of different sizes and weight, it is important to consider the contextual factors. A stock keeping unit (SKU) is the smallest physical unit of a product that is tracked by an organization. Thus, when formulating solutions on how to manage the wastes and bottlenecks, it is important to align the configurational elements with the contextual factors to increase the picking performance. As the overall goal is to improve the capacity of the pickers, a holistic view is necessary, which is why the focus will be on picking process but the also the related processes of put-away and distribution that influences the picking operation.

1.4 Purpose & Research Objectives

The purpose of this thesis is *to develop a solution for how to increase warehouse picking efficiency by identifying and solving material-flow bottlenecks and wastes related to the picking process*. The following research objectives (ROs) have been formulated to fulfil the purpose above:

RO1: *Develop an artifact based on contextual factors and lean practices to improve warehouse picking performance.*

It is necessary to develop an artifact in terms of a theoretical framework that is based on prior theories as there is a gap in the literature today on how to use lean practices in a warehousing context. Lean practices are suitable as they aim to increase performance through continuous improvements of the material flow, which involves bottlenecks and wastes. Contextual factors are also suitable as the context is hard to change and decisions need to be aligned with the context to improve the performance. Thus, contextual factors and lean practices are included in the artifact. The lean principles can be used to find areas to improve, meaning bottlenecks and waste. Contextual factors can support with solving the bottlenecks and wastes by aligning the configurational elements with the context. This approach can increase the warehouse picking performance.

RO2: *Test and evaluate the artifact by applying it to the Tetra Pak production warehouse.*

To understand how the artifact performs and if it fulfils its purpose, it is important to test and evaluate it in a practical situation. Thus, the artifact will be tested at the company with the initial business need, which is Tetra Pak. It will be used to guide the collection and analysis of the data. The data collection will include a description of the current state of the warehouse, such as its warehouse design, equipment, operations, activities, and performance. The value stream map will be used to give an overview of the warehouse processes and its data. The collected data is necessary for the analysis that will identify bottlenecks, wastes, and contextual factors related to the picking performance of the current situation. Based on this, it is possible to understand how configuration is already aligned with the contextual factors, as well as where there are mismatches which contributes to loss of performance and wastes. Thus, general design propositions can be formulated to understand how to increase picking efficiency in certain context, which will guide the case company on how they can improve their picking performance.

1.5 Focus & Delimitations

The scope of this thesis will be to analyse the material flow in the north warehouse, south warehouse, and yard of the case company. An artifact will be created to support the analysis and aims to improve the picking process of a warehouse by focusing on bottlenecks and waste, as well as the contextual factors and configurational elements. The scope is seen in Figure 1.

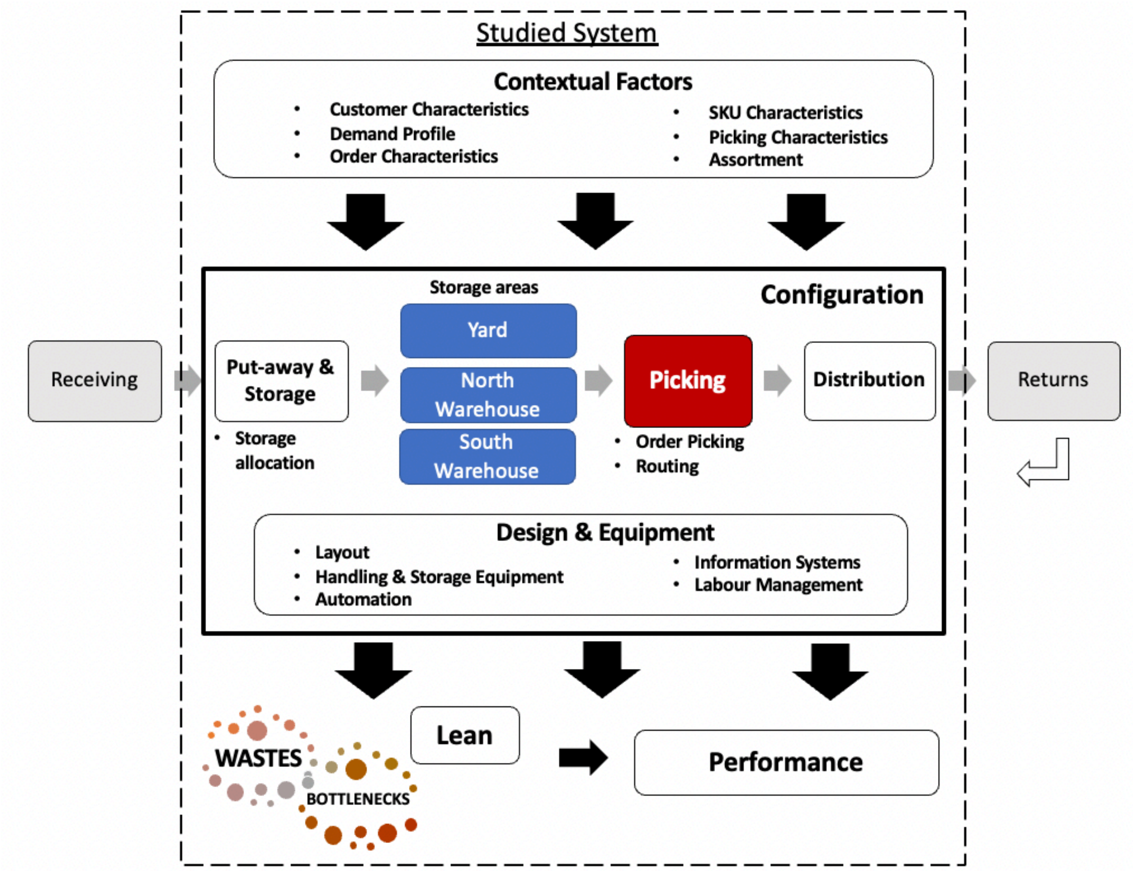


Figure 1. Illustration of the scope of the study (inspired by Kembro, Norrman and Eriksson (2018), Kembro and Norrman (2019), and Kembro and Norrman (2020).

Since the overall goal is to improve the picking performance of the warehouse, the focus will be on picking. However, put-away and distribution will be included in the scope because they are interlinked with the picking activity and affect its performance. As bottlenecks, wastes, contextual factors, and configurational elements are linked to the performance of the warehouse, they are all included in the scope. The configurational elements consist of the warehouse design, equipment, and operations. The scope will also include the warehouse, in terms of the south and north warehouse, and the yard. A current state of the material flows within the scope will be identified and recommendations for improving the picking performance will focus on them.

Due to the time constraint of 20 weeks, it is necessary to limit the thesis, which is done in several ways. Firstly, the scope focuses on the picking process and its closest interrelated processes, that is put-away and distribution. Other operations in the warehouse such as quality control, kitting, and inventory control is not included in the scope. The study also focuses on orders that are picked towards the production, and not to customers. Secondly, the suppliers and the production will not be part of the analysis. Thirdly, the focus on other flows such as the information flow will be secondary. Fourthly, the suggestions on improvement will not include an implementation plan, cost-benefit analysis or change management. Lastly, the artifact can be tested at other warehouses to increase trustworthiness, but due to the time constraint it is limited to be tested at the company with the initial business need. These restraints are necessary for the study to be possible.

1.6 Disposition

The thesis report has six chapters, which are presented in Figure 2, where the three first chapters are the introduction, methodology, and frame of reference. The introduction provides background on the research topic, as well as the purpose and research objectives. The scope is also clarified in this chapter. The next chapter, methodology, clarifies the research strategy and design used in this study, as well as the methods used for data collection and data analysis. The quality of this study in terms of reliability and validity is also discussed. The third chapter, the frame of reference, presents prior theories that are relevant to the research subject. It includes warehouse theories such as operations, design, and equipment. It also describes theory related to contextual factors, which includes activity profiling as a mean to understand the context, and performance as it is affected by the context and configuration. Furthermore, the frame of reference chapter describes lean practices in terms of wastes, value stream mapping and bottleneck management. The third chapter ends with presenting the artifact that is based on the theories in the frame of reference and aims to increase the picking performance of a warehouse.

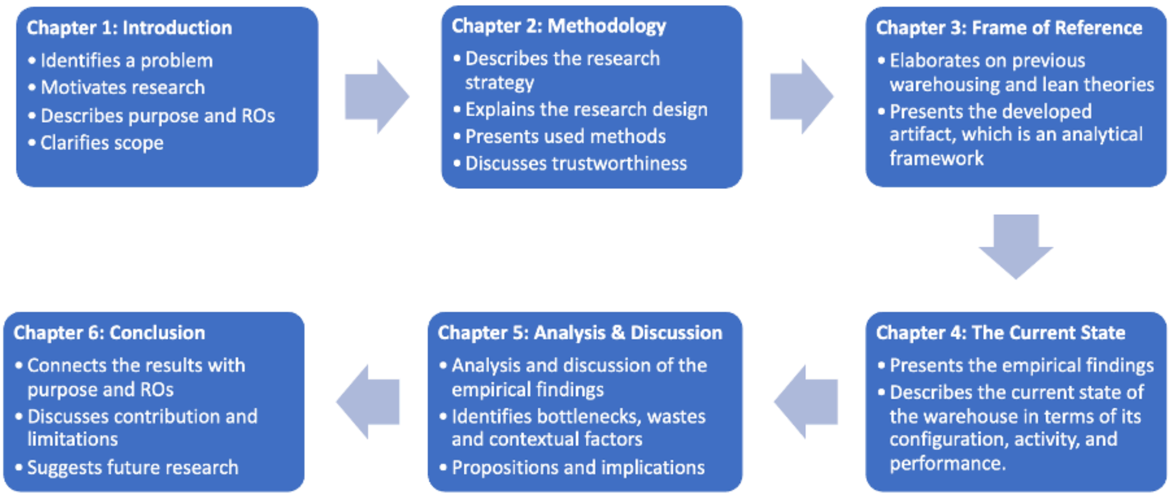


Figure 2. Overview of the different chapters of the thesis report.

The thesis continues with the chapters related to the empirical findings and the analysis where the artifact is applied by supporting the data collection and analysis. The fourth chapter describes the current state of the case company warehouse with the help of empirical findings, which involves a current value stream map that summarizes the current state. It visualises the material flow and its processes, and data connected to the warehouse operations that are relevant for this thesis. The fifth chapter presents and discusses the analysis that was done with the help of the artifact. The identified bottlenecks, wastes, and contextual factors are presented, as well as propositions on how to improve the picking performance in a certain context. The practical implications that the proposition have on the case company are also discussed.

The last chapter presents the conclusion of the study in terms of its theoretical and practical contribution, which are related to the purpose and ROs. The paper ends with a discussion about future research.

2. METHODOLOGY

This chapter describes the methodology that is used to fulfil the purpose and research objectives of the thesis. The first section clarifies the chosen research strategy, which is design science. That is followed up by the research design, which includes the methodology and process of the study. The third describes the different data collection methods. The fourth section explains the methods used for the data analysis. The chapter ends with discussing the research quality of the study in terms of its validity and reliability.

2.1 Research Strategy

A research strategy is necessary for the thesis because it provides a sense of direction for the researcher by outlining an overall plan for how the research study is conducted. There are several different research strategies, and it is important to choose a suitable one that is based on the purpose and research questions, which Saunders, Lewis and Thornhill (2007) highlight. They also mention that other factors need to be considered, such as existing knowledge within the field, time limitations, available resources, and research approaches.

Design science is used as the research strategy for this thesis because it is appropriate with the purpose of the study. The purpose is to develop a solution for how to increase warehouse picking efficiency by identifying and solving material-flow bottlenecks and wastes related to the picking process. Dresch et al. (2014) state that design science is a problem-solving approach, and it aims to enhance scientific knowledge by developing new solutions to solve real-world problems and make scientific contributions. They also highlight that the research strategy is suitable for studies in an organizational context, where you want to solve a practical problem and contribute with knowledge at the same time. This fits well with the purpose of the thesis project because it involves designing an artifact for solving material-flow bottlenecks and wastes related to the picking process. The overall purpose of the thesis also aims to contribute with scientific knowledge in terms of lean practices in a warehousing context. Dresch et al. (2014) also point out that design science research does not need to have an optimal solution, but a satisfactory solution based on the conditions, which is suitable because of the time restrictions and limitations of the thesis project. Furthermore, Romme and Dimov (2021) underline that the objective of design science is to transform current situations and systems into improved or wanted states. They explain that the science element of the design science is about making sense of the current state of the world and the design element is related to making a future state. This aligns with the purpose as the developed artifact need to involve an understanding of the picking performance in its current state to develop solutions for a better future state.

A design science approach has mainly been used in information systems research, but researchers highlight that, it can be applied to other fields as well (Dresch et al., 2014; vom Brocke, Hevner and Maedche, 2020). Researchers in the field of operations management highlight the importance and need of using a design science research strategy when studying issues in operations management (Holmström, Ketokivi, and Hameri, 2009; Van Aken, Chandrasekaran, and Halman, 2016). They mean that such an approach can create a better bridge between research and practice that is necessary in the operations management field. Thus, design science research in operational management is still developing. Furthermore, Van Aken, Chandrasekaran, and Halman (2016) emphasize that the strategy is about developing knowledge that can be used for designing actions, processes or systems that aims at achieving desired outcomes, which is developed by studying real-life issues. They also stress that it is a research strategy and not specific methods for data collection and analysis, and therefore it can be conducted in various of ways.

There are different design science approaches. According to Romme and Dimov (2021), design science research is divided into four acts: framing, creating, theorizing, and validating, where the two first acts belong to the design element and the two last acts belong to the science element. Framing means exploring ideas that can help identify and understand the problem and solution space. Creating is about developing innovative artifacts and is often connected to framing due to iterations back and forth between the two activities. Theorizing refers to the development of key concepts to generalizable models that can be applied to other situations. Validating involves the act of evaluating artifacts and different methods used, but the purpose is to investigate whether and why the artifact does what it was intended to do. The authors emphasize that design science research can start in any of these acts and move between the acts as many times as necessary. Furthermore, Hevner et al. (2004) means that design science research in the field of information system is supported by an environment and a knowledge base. The environment defines the problem space, which means the context where the relevant problem exists and that includes the people, organizations, and technology. This provides relevance to the research. The knowledge base consists of foundations and methodologies, meaning the theoretical and methodological building blocks needed to do the study and develop new artifacts. By applying previous theories and methods appropriately, rigor is achieved.

Peffers et al. (2007) also clarifies the process of design science research, which consists of six activities. The first activity involves the definition of a research problem and justification of its relevance, while the second activity is about outlining the objectives of a solution, either quantitative or qualitative, based on the research problem and the current knowledge. Activity three focuses on the creation of an artifact and activity four on the demonstration of that artifact and its usefulness to solve the problem, which can be simulations, case studies, or other relevant activities. The fifth activity is the act of observing and measuring the performance of the artifact based on the demonstration. The final activity means that the study needs to be communicated to relevant audiences.

The design science approach used in this thesis project is seen in Figure 3, which is based on Romme and Dimov (2021), Hevner et al. (2004), and Peffers et al. (2007).

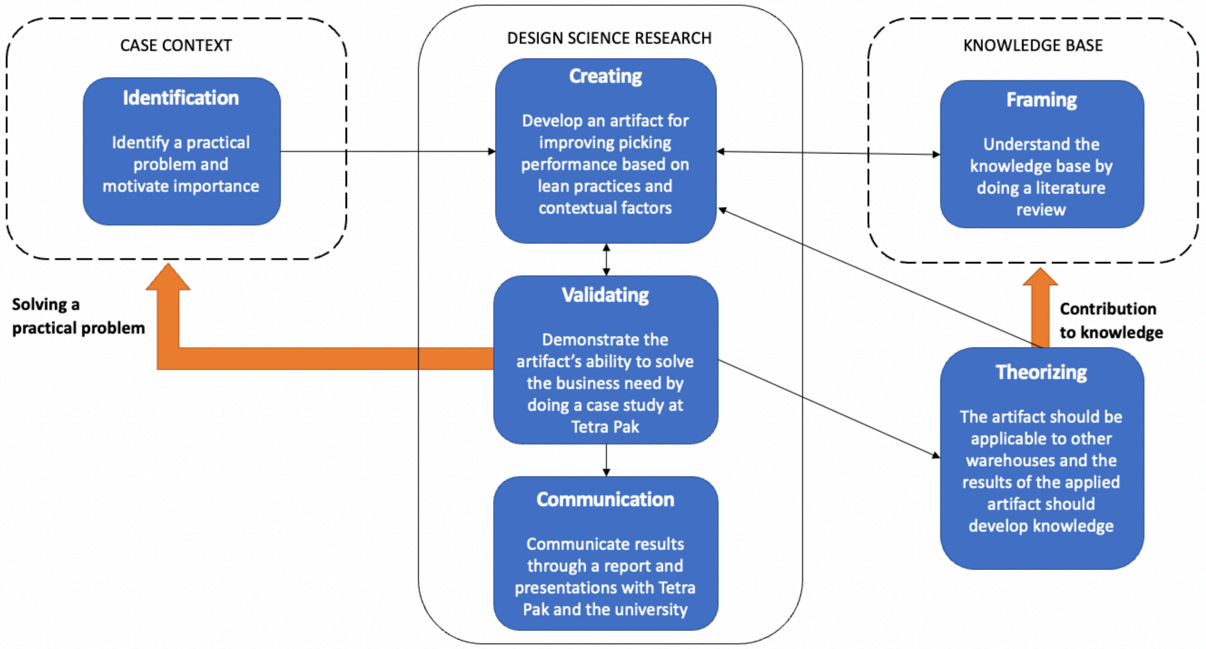


Figure 3. The design science approach of the thesis project.

The study starts with identifying a practical problem and motivate the research topic. This is connected to the environment, which defines the problem space and business need. This means that a business need at Tetra Pak was identified, together with a research gap which motivates this study. After the identification of a practical problem, the artifact is going to be developed. The artifact is going to be based on previous knowledge on different areas that are relevant such as lean practices and contextual factors. Thus, the knowledge base provides appropriate theories and frameworks, which are used to create an artifact. This would also mean an iterative process between framing and creating, as well as validating as missing gaps became apparent when collecting and analysing the data. This means that the artifact was adjusted throughout the process of the study to become as complete as possible. Theorizing also occurs because the artifact should be applicable to other practical situations and not only Tetra Pak. Thus, the artifact contributes to the knowledge base.

After the development of the artifact, the artifact must be demonstrated in a suitable context. This study applies the artifact at Tetra Pak's production warehouse to solve their problems concerning material-flow bottlenecks that affects the picking performance. This also allows the possibility to evaluate the performance of the artifact by understanding how recommendations are developed. In other words, a case study is conducted for applying and validating the artifact, where the artifact guides the collection and analysis of the data. By applying the artifact, knowledge on lean practices in warehousing is developed and can be used for theorizing, which contributes knowledge to the field. The reason why a case study is chosen is further described in the next subchapter 2.2. The last step, communication, involves a report and presentation of the study to both the case company and the university.

Design science often includes the context-agency-mechanism-outcome (CAMO) format (Romme and Dimov, 2021). This is used to get a deeper understanding of how design and science relates to each other. Romme and Dimov (2021) stress that if knowledge is going to be developed into a conceptual tool that is useful and applicable in practice, it must be connected to practical situations in terms of implementation and application. This requires specifications such as context, actions, mechanisms, and outcomes. The CAMO format supports problem-solving by systematically considering if these specifications are suitable and valid. For example, it can be used to explain empirical phenomenon in theory or develop design principles that guide the creation of new artifacts. The latter has been of relevance in this thesis as it has helped to formulate design propositions based on the context, and the recommendations are based on these to give suitable solutions. Table 1 clarifies the definitions of each specification and how they relate to each other. It also explains the OCAM format, which Romme and Dimov (2021) highlight as a rewritten form of CAMO that is more of a design principle.

Table 1. CAMO definitions and relationships (Romme and Dimov, 2021, p.9).

	Context	**Agency**	**Mechanism**	**Outcome**
Definitions	Conditions that can enable or constrain behaviour and choices.	The actors and their actions in a context.	The driver that gives rise to a particular king of outcome.	The intended or unintended results of the combined ACM.
CAMO proposition	*"If in context C agency A activates mechanism M, this is likely to generate outcome pattern O".*			
OCAM proposition	*"To generate outcome pattern O in context C, do something like A to activate mechanism M".*			

2.2 Research Design

The thesis also needs a research design, which is about the design of the study in detail. This includes developing a plan on how to fulfil the purpose and research objectives. This is especially important for design science since it is only a research strategy without any specific methodology for data collection and data analysis, which means that it can be conducted in several ways. The research design will be a combination of design science and case study aspects as the research strategy is design science and the methodology of a case study will be used because the artifact is going to be validated through a case study. The subchapter will begin with elaborating on the choice of a case study methodology and then describe what a case study is, as well as present its advantages and disadvantages. It will also discuss how a case study can be conducted and how the research design looks for this thesis.

There are different research methods that can be used to evaluate the artifact. Yin (2014) list five major research methods and the situations when they are suitable, which is seen in Table 2. The situation where each is suitable depends on three conditions: The form of the research question, the extent of which the investigator can control behavioural events, and if the study focuses on contemporary or historical events. According to Yin (2014), a case study is suitable when wanting to study a phenomenon by asking "how" and "why" questions, and study contemporary events in a real-life context, where the researcher cannot manipulate behaviour.

Table 2. When different research methods are suitable (Yin, 2014).

Method	**Type of research question**	**Requires control of behavioural events?**	**Focuses on contemporary events?**
Experiment	How, why?	Yes	Yes
Survey	Who, what, where, how many, how much?	No	Yes
Archival Analysis	Who, what, where, how many, how much?	No	Yes/No
History	How, why?	No	No
Case Study	How, why?	No	Yes

This thesis project is about examining the picking process in a production warehouse and study how it can be improved. It focuses on contemporary events and the behaviour is hard to control. Thus, a case study is a suitable research method to examine the artifact. Furthermore, Hevner et al. (2004) also list several methodologies for evaluating an artifact based on the knowledge base. One of the mentioned methods is case study, which aims to study the artifact in depth in a business context. Since the developed artifact in this study is a framework that is supposed to be applied in a business environment, it is suitable to test it at a case company. Thus, this also suggests that a case study is appropriate.

Yin (2014) gives two definitions of a case study, which can be used to understand what a case study is. The first definition is related to the scope of a case study, which is based on the discussion above. This means that a case study is an empirical in-depth investigation of a contemporary phenomenon within its real-world context and contextual conditions. This study aims to understand a real-world case as well as investigate the context that it operates in. Furthermore, the second definition is about the methodological characteristics of a case study. This definition includes that the results can be based on multiple sources of evidence but also from prior development of theories that guides data collection and analysis. This is suitable because the study will require previous theories to create the artifact and empirical findings related to the case.

Meredith (1998) underlines three strengths with the case study approach. These are described in Table 3 together with explanations on how they relate to this study. Furthermore, Yin (2014) highlights that the unique strength with a case study is its ability to deal with a variety of evidence, such as documents, artifacts, interviews, and observations. Meredith (1998) also stress that a case study can both use quantitative and qualitative approaches to collect evidence. The author emphasizes that the goal is to understand the phenomenon as much as possible by having multiple sources of evidence supporting the same fact.

Table 3. Benefits with case study approach and its relevance (Meredith, 1998).

Benefits	**Appropriateness for the study**
By studying the phenomenon in its natural setting, the created knowledge is based on observations of practical situations.	The artifact can be applied and studied in a business environment. The generated knowledge from the case study is based on practice.
Answers questions of what, how and why with a relatively complete understanding of the phenomenon, in terms of its nature and complexity.	Questions such as: “how well does the artifact perform”, “what problems does the artifact fix” or “why does the artifact work” can be answered.
The approach is suitable when the phenomenon is not completely understood and where exploratory studies are relevant.	The phenomenon regarding bottlenecks in warehouses, as well as the innovative artifact are uncertain matters.

Even though a case study can look different because of their different ways to collect data, there is often an overall process which a case study follows. Voss, Tsikriktsis and Frohlich (2002) provide guidelines and a roadmap for how to design, develop, and conduct a case study, which is summarized in Figure 4.

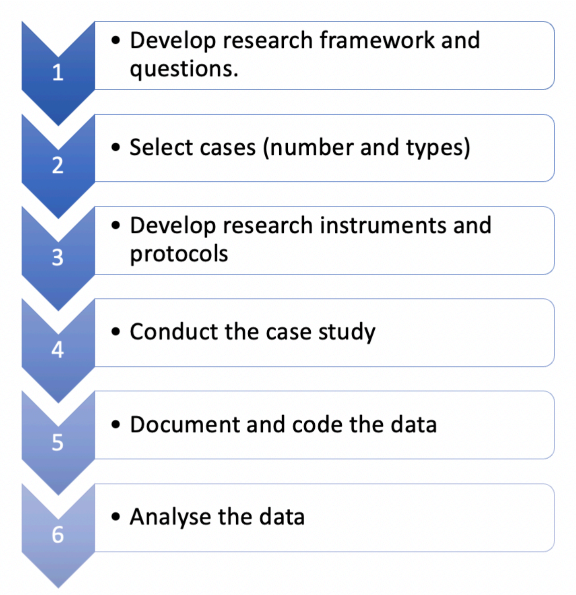


Figure 4. Case study research process, adapted from Voss, Tsikriktsis and Frohlich (2002)

Furthermore, Voss, Tsikriktsis and Frohlich (2002) highlights the advantages and disadvantages with different number of cases. This is seen in Table 4. As the thesis aims to test the artifact and improve the picking efficiency, a single case will be used to achieve great depth. This is also appropriate due to the limited time of 20 weeks.

Table 4. Advantages and disadvantages with different types of case studies (Voss, Tsikriktsis and Frohlich, 2002).

Type of case study	**Advantages**	**Disadvantages**
Single cases	Greater depth	Limits the generalisability of the conclusions. Greater risk of bias such as misjudging the representativeness of a single event and exaggerating easily available data.
Multiple cases	Augment external validity, help guard against observer bias.	More resources are required, less depth per case.
Retroperspective cases	Allow collection of data on historical events.	May be difficult to determine cause and effect, participants may not recall important events.
Longitudinal cases	Overcome the problems of retrospective cases.	Have long elapsed time and thus may be difficult to do.

This thesis project follows the overall process by Voss, Tsikriktsis and Frohlich (2002), which is shown in Figure 4, for conducting the case study with the aim of testing and evaluating the artifact. Figure 5 shows the procedure of the study, in other words the research design.

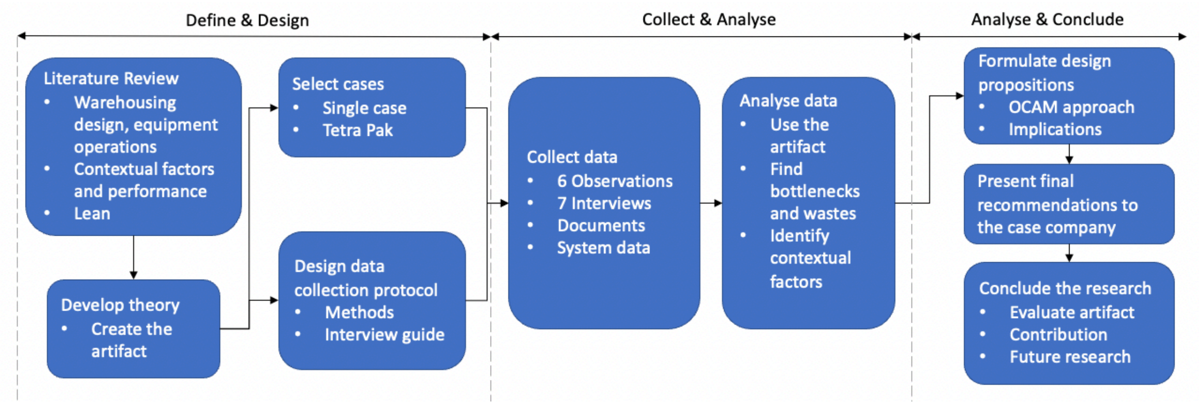


Figure 5. The research design, inspired by Yin (2014), and Kembro and Norrman (2019).

When conducting a case study, it is important to define the unit of analysis. Yin (2014) explains that the unit of analysis is the phenomenon that is going to be studied and that it should reflect the purpose and research questions of the study. He also highlights that different units of analysis requires different research designs and data collection methodologies. Thus, it is important to define the unit of analysis correctly. In this study, the unit of analysis is the picking efficiency of the production warehouse at the case company because the artifact is applied to collect and analyse data about the performance and what affects it. This reflects the purpose which is to design a solution for identifying and managing material-flow bottlenecks in the picking process of a warehouse to improve the picking capacity.

2.3 Data Collection

Several methods have been used to collect the data in this study. Figure 6 gives an overview of how the different data collection methods have been used. The artifact, which is based on previous theoretical findings, plays a role in the collection and analysis of data. The artifact guides *what* data that should be collected, and the data collection methods explains *how* data have been collected when applied to the case company. The collected data can then be analysed with the help of the artifact to suggest recommendations to the case company on how to improve their picking performance. Table 5 gives a brief overview of the used data collection methods, as well as their data type and purpose.

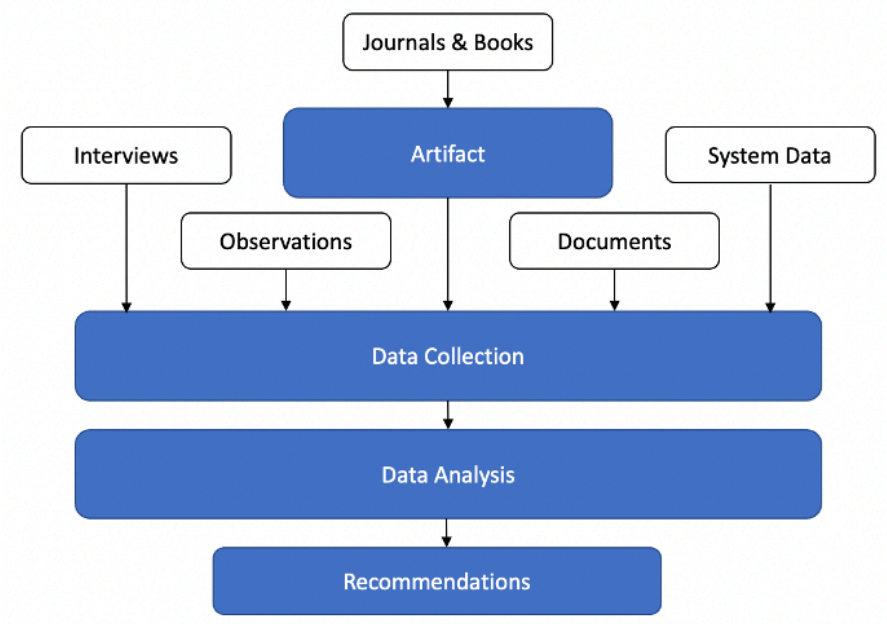


Figure 6. How the different data collection methods have been used.

Table 5. Data collection methods used in the study.

Method	**Data type**	**Purpose**
Literature (scientific articles and books)	Qualitative; Secondary data	Gather prior development of theories to create an artifact.
Direct observations	Qualitative; Primary data	To collect data about the processes for the value stream mapping
Interviews	Qualitative; Primary data	To get a deeper understanding of the warehouse, such as its operations, design, and equipment.
Documents	Qualitative & Quantitative; Secondary data	To get a deeper understanding of the warehouse, such as its operations, design, and equipment.
System data	Quantitative; Secondary data	To collect numerical data about the warehouse for the contextual factors and value stream mapping.

Both qualitative and quantitative methods have been used to collect data. Quantitative data focuses on numbers and qualitative data focuses on non-numerical data, such as words or pictures (Saunders, Lewis and Thornhill, 2007). Data collections methods in a case study can be both quantitative and qualitative because the aim is to triangulate multiple sources of data (Meredith, 1998; Saunders, Lewis and Thornhill, 2007). Triangulation means to have several sources that support the same evidence, which assures that the collected facts are accurate. This is important in a case study because the aim is to get a as complete picture as possible of the studied phenomenon (Meredith, 1998). Voss, Tsikriktsis and Frohlich (2002) highlights that triangulation can increase the trustworthiness of the study. Furthermore, Yin (2014) stresses that one strength with case studies is that it can handle evidence from different sources such as documents, interviews, and observations.

This study uses both primary and secondary data. Saunders, Lewis and Thornhill (2007) write that primary data is when new data is gathered specifically for the purpose of the study. They also state that secondary data is data that has already been collected for another purpose than the study, but this data can still be a useful source for other studies. Examples on secondary data could be documents, books, journals, and surveys, while primary data could be observations, interviews, and questionnaires. Furthermore, they highlight that both data types can be useful for case studies because it allows triangulation.

2.3.1 Literature Review

The literature review has several functions of this thesis. Saunders, Lewis and Thornhill (2007) highlight that literature can be used to generate and refine research ideas. By reviewing academic articles, it has been found that there exists a research gap on lean practices such as value stream mapping and bottleneck management in a warehousing context. This motivates a study on the research topic. Furthermore, the authors stress that a literature review demonstrates previous knowledge and limitations on the relevant subjects. This needs to be considered because a new study is going to be related to this current state of knowledge. Additionally, when designing an artifact, the knowledge base needs to be considered to achieve rigor (Hevner et al, 2004). Thus, the artifact is created with the help of the literature review and is based on theories such as warehousing, lean practices, and contextual factors. This artifact should be applicable in a warehouse context to analyse and solve bottlenecks.

The literature review was conducted in three phases. The first one was to get an understanding of the subjects to see where a potential study could be suitable. During this stage the research topic was identified, along with the purpose and research objectives. The second stage was to gather knowledge about the subject to create the foundation of the artifact. As the research design involves iteration between the framing, creating and validating act, it means that an additional literature review was conducted. The aim was to fill in the missing parts of the artifact and develop it to a complete and satisfactory solution.

The reviewing process involved critically study academic articles and books. To find literature, a database that contains all resources of the Lund University libraries was used, called LUBsearch. By searching on terms related to the subject such as *bottleneck management in warehousing* or *value stream mapping*, the database provided relevant resources. To critically assess these, the authors were examined, as well as the journal that published the paper. In addition, literature was inspected by its use of references to other sources and if it was well structured and written. Furthermore, the most recent published papers were reviewed first to get the most updated status on the topic. The papers also referred to previous articles, which hinted on literature and authors that have had a major impact on the subject. Thus, it resulted in additional resources to review. To increase the trustworthiness of this thesis, it was important to use primary sources when possible. Additionally, some key references are used in this thesis project because they give a detailed overview of some topics. One of these resources is the book by Bartholdi and Hackman (2019), called *Warehouse and Distribution Science*, which gives significant insight on the fundamentals of warehousing. Sources from Rother and Shook (1999), Langstrand (2016), and King (2019) have mostly been used for the lean principles such as waste, bottlenecks and VSM. Furthermore, the contextual factors in a warehousing context were understood through Kembro, Norrman and Eriksson (2018), and Kembro and Norrman (2020).

2.3.2 Observations

Observing is one of the data collection methods that is used to gather primary qualitative data. Saunders, Lewis and Thornhill (2007) highlight that observation can provide some useful data to a study and is suitable for when it is necessary to study people and their behaviour. The authors distinguish between participant observation and structured observation. The first focuses on qualitative data, where the researcher participates in the activities of the subject and becomes a member of the organization. Structured observations focus instead on quantitative data and the frequency of events. The approach often has a more pre-determined structure than participant observations. Voss, Tsikriktsis and Frohlich (2002) also mention another type of observation called direct observations, which can be formal or casual. They mean that data can be collected through direct observations of things such as processes or meetings, and it can be a structured processes analysis or an unstructured observation.

The observations conducted in this study are mostly through direct observations, where some are more structured than others. The data gathered from the observations lays the foundation for the current state of the warehouse. Thus, the less structured observations enable studying the phenomenon in its natural setting with no attended goal, while a more structured observation can provide data where it is lacking. Table 6 summarizes the observations that were conducted.

Table 6. Conducted observations of the study.

Observation	Date	Purpose	Additional attendee(s)
Introduction tour	2021-11-01	An overview of the processes, operations and people involved to get a better understanding of the warehouse and its business need.	Warehouse & Packing Manager, Warehouse & Forklift Leader
Picking process	2021-11-04	Worked as a picker at the vertical storage lifts to understand the process.	Warehouse workers at the vertical storage lift
Picking process	2022-03-09	Get a deeper understanding of the picking process of the vertical storage lifts and pallets racks	Warehouse workers in the picking team
Warehouse layout	2022-03-09	Understand the layout and the different storage locations of the south and north warehouse	None
Yard layout	2022-03-09	Understand the layout and the different storage locations of the yard	None
Layout and storage locations	2022-03-10	Get a deeper understanding of the storage locations at the north warehouse and in the tube processing area	Warehouse & Packing Specialist

2.3.3 Interviews

Interviews are conducted to gather data from the people that work at the warehouse. Saunders, Lewis, and Thornhill (2007) explain that interviews can be varied in terms of how structured they are and distinguish between three types: structured, semi-structured and unstructured interviews. Structured interviews use a pre-determined set of questions, which are the only questions that should be asked during the interview. Semi-structured interviews also have pre-determined questions or themes but as the interview progresses, it is allowed to ask additional questions or change the order of questions. Thus, a semi-structured interview can be adapted to the responses of the interviewee and the flow of the conversation. Unstructured interviews are informal with no pre-determined questions. Instead, a general idea about a topic is explored in depth.

In this study all types of interviews are conducted to gather data. Unstructured interviews are used in the beginning of the study when having informal discussions with the workers, where no questions have been formulated beforehand. These can be meetings with the company or shorter informal discussion that can take place in person, over phone or email. As it was possible to work at the site, informal discussions could arise which hinted on useful areas to collect data. However, semi-structured interviews are mainly used due to its flexibility. Since this study covers many elements of the warehouse, there might be findings during the interview that were not intended but still of interest. Thus, a semi-structured approach makes it possible to investigate further into those findings. Smaller structured interviews are used in the later stage of the study, when the direction of the study has been clearer and more specific questions needs to be asked that has been developed during the analysis stage.

During the interviews, notes are taken to document the responses. Recording and transcribing the interviews is discarded to create a as comfortable interview situation as possible and because it is a time-consuming process. It is also possible to cross-check facts with the interviewee or other people at the company, and triangulation is necessary during the study. In addition, the findings will continuously be reviewed by the supervisor at Tetra Pak that will confirm them and give further advice on relevant data. Thus, recording and transcribing does not seem necessary in this situation. Table 7 summarizes the conducted semi-structured interviews. All the interviews were conducted on site, except the first interview in February, which was conducted remotely through WebEx. The used interview guide is shown in Appendix A.

Table 7. Semi-structured interviews that were conducted in this study.

Semi-structured Interviews	**Date**	**Duration**	**Purpose**	**Interviewee**
Operations, layout, and equipment	2022-02-25	45 min	Get an overall picture of the operations of the warehouse. Get a deeper understanding of the layout and resources at the warehouse	Warehouse & Packing Specialist
Operations	2022-03-09	90 min	Get a deeper understanding of the put-away, picking and distribution processes of the south and north warehouse.	Four warehouse workers in the picking team
Layout and storage locations	2022-03-09	30 min	Understand the layout and different storage locations	Warehouse Analyst
Labour management, and storage locations	2022-03-10	60 min	Understand the labour management strategies used at the warehouse. Also, get more information on the storage locations in north warehouse and in the tube processing area.	Warehouse & Packing Specialist
Yard	2022-03-10	30 min	Get a deeper understanding of the operational processes of the yard. Also, get information on storage locations.	Yard Responsible
Handling equipment, and picking process	2022-03-17	60 min	Understand more about the trucks, picking process and picking errors.	Warehouse & Packing Specialist
Information systems, and performance	2022-03-28	60 min	Get more knowledge on the information systems that are used in the warehouse and the performance of the warehouse	Warehouse Analyst

2.3.4 Documents

There are several different types of documents from the case company that have been used to gather information, which is seen in Table 8. The data gathered is mostly secondary and qualitative data. The company's standard operating procedure (SOP) explains the working process at different warehouse stations. Thus, it provides a detailed overview of the different processes and stations at the warehouse. It is helpful when mapping out the current state. However, it is important to triangulate the facts because they can be outdated. Other useful documents are maps of the company site as well as the warehouse.

Table 8. The different documents used in this study.

Documents	**Type of document**	**Description**
Layout	Qualitative	Maps of the south warehouse, north warehouse, and yard, and their storage locations.
SOP Vertical storage lift Picking	Qualitative	The working process of the picking from vertical storage lifts
SOP Pallet Picking	Qualitative	The working process of the picking from pallet locations in the south warehouse and north warehouse
SOP Yard Picking	Qualitative	The working process of yard responsible
SOP Distribution	Qualitative	The working process of the distribution of finished orders
Logged picking data	Quantitative	Excel-file containing different transfer orders, the number of pick-lines and the time it took to pick. The data has been logged by the pickers of the lift and pallets. It was used to get the order characteristics.
Previous picking data analysis	Quantitative	PowerPoint containing the number of pick-lines for a type of machine. It was used to get the order characteristics. Also, includes estimated put-away time.
Pick errors	Qualitative/ Quantitative	PowerPoint containing an analysis about pick errors between Q1-Q3 2021. Used for picking characteristics.
Additional shelves in lift	Qualitative/ Quantitative	PowerPoint containing an analysis about additional shelves in lift 48 and 49.

2.3.5 System data

The system data of the company refers to the quantitative data that was retrieved from the company's information system in terms of their ERP system with a WMS module and business intelligence system. Table 9 gives a detailed overview of the data that was retrieved. The quantitative data made it possible to do an activity profile of the warehouse that was needed to develop a VSM and identify contextual factors. Most of it was retrieved from the ERP system, except the data about seasonality and pick errors, which was from the BI system.

By gaining access to the different information systems, and with the support from the warehouse analyst, different quantitative data could be retrieved. The data could be extracted to an Excel file, which made it easier to work with. The time period that was chosen mostly was six months back, meaning September 2021 to February 2022, because it reflects the most recent data of the warehouse. However, it was only possible to gather snapshots of the current moment in some situations, otherwise the history would have been used. Also, when presenting the data in the empirical findings chapter, some graphs or tables include shorter time periods to avoid too much information that are not necessary and will only make things hard to interpret. Some of the data needed to be cleaned as well. For example, some transfer orders have been deleted and gotten new transfer order numbers. Also, some pick-lines are shown several times in a transfer order because of the bill of materials. This means that pick-lines with the same transfer order, material number, and storage bin has been deleted because they are just one pick. Furthermore, some storage types are excluded from the scope and materials from those locations have been deleted. This includes claims.

Table 9. Overview of the data that was acquired.

Data	Description	Time period
Space utilization and storage locations	Snapshots of the space utilization for the current day, which were used to see the space utilization for the different storage types of the warehouse. Also, used for identifying the different storage types in the warehouse and the storage bins.	2022-03-02 2022-03-28
Confirmed picks-lines	The pick-lines that were confirmed between September 2021 to February 2022. This was used to understand the picking characteristics of the warehouse.	2021-09-01 to 2022-02-28
Created pick-lines	The pick-lines that were created between September 2021 to February 2022. This was used to understand the picking characteristics, SKU popularity of the warehouse, and the service level.	2021-09-01 to 2022-02-28
Inventory data	This gave a snapshot of what is currently stored in the warehouse. It was used to get empirical material on the SKU characteristics.	2022-03-09
Seasonality	This was retrieved from their BI system and shows the number of picks during 2021 to see if there is seasonality.	2021
Created put-away lines	The put-away lines that were created between September 2021 to February 2022. This was used to understand the put-away characteristics and the new SKUs that are introduced to the warehouse.	2021-09-01 to 2022-02-28
Pick errors	This was retrieved from their BI system and shows the number of pick errors in 2021.	2021-01-01 to 2021-12-31
SKU data	A list of all the materials registered in the system and their characteristics such as they primary storage bin and maximum number of units in that bin.	2022-03-09 and earlier

2.4 Data Analysis

After collecting the data, but before analysing it, the data need to be organized. According to Voss, Tsikriktsis and Frohlich (2002), it is necessary to document and code the collected data after it has been retrieved. Documentation includes putting together documents, typing up notes and/or transcribing recordings, which creates a case narrative. Coding is about categorizing the data to compare and relate concepts to each other, which creates theoretical properties. The authors highlight that documenting and coding makes it possible to analyse the patterns of the case data.

Saunders, Lewis and Thornhill (2007) stress that both qualitative and quantitative data needs to be analysed to be useful and create meaning, in other words they need to be turned into information. The different types of data need different approaches for analysis. Saunders, Lewis and Thornhill (2007) explain that analysis of qualitative data involves categorization and identification of relationships between categories to develop concepts. They also describe that analysis of quantitative data involves describing and exploring data and its relationships, which can be done by statistical tools, tables, charts, and graphs.

Yin (2014) also emphasizes the importance of analysing the data, but that it is one of the least developed features of conducting case studies. The author stresses the importance of having a general analytical strategy that guides you through the analysis. The aim is to link the empirical findings with interesting concepts which will give a sense of direction when analysing the data. There are different general strategies, and one is about relying on prior theories (Yin, 2014). This strategy is about following the theories that the objectives and design of the study were based on. This also reflects the research questions, literature review, and new hypothesis or propositions that have shaped the data collection protocol. This study will use this general strategy because this study is about testing an artifact that has been created based on prior theories. Thus, a new theoretical framework has been developed, which guides the data collection as well as the analysis of the data.

The purpose with the created artifact is to analyse bottlenecks in the picking process of a warehouse and propose suitable recommendations to increase the picking performance. Thus, the artifact will combine lean tools such as VSM, bottleneck management, and waste analysis, together with contextual factors to understand where improvements are necessary and what solutions are appropriate. Therefore, these will work as analytical tools and guide the analysis of the data collection. This means that the artifact is used to guide both the data collection and the data analysis. Figure 7 shows an overview of the artifact with the different theoretical areas and how they are related to the data collection and data analysis. As the artifact is based on the literature review, it is described in detail in the final section of the frame of reference section.

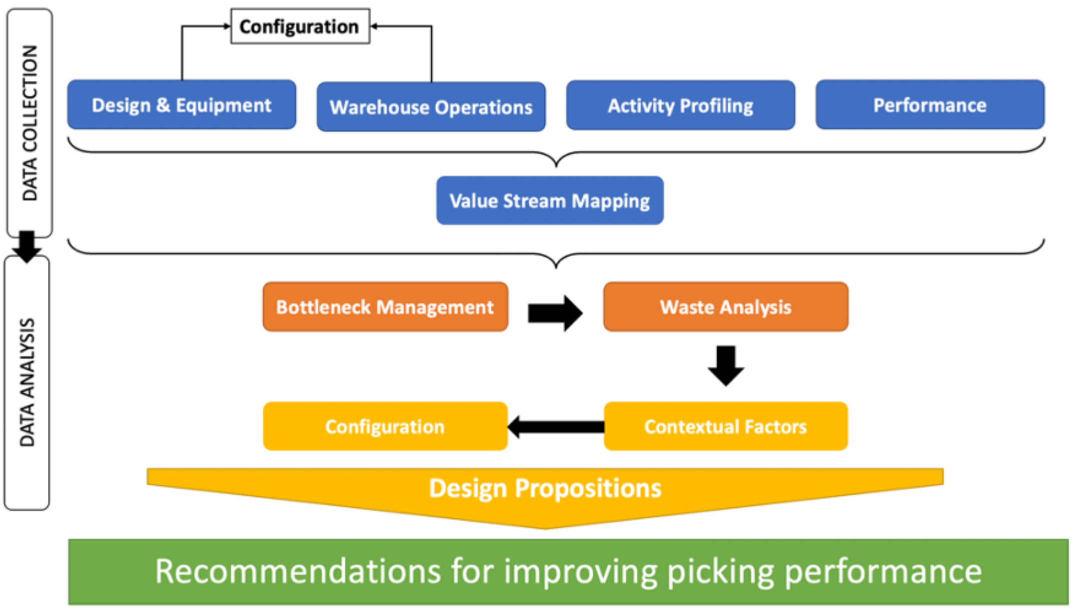


Figure 7. The different theories involved in the artifact.

Furthermore, Yin (2014) highlight that within any general strategy, an analytical technique should be considered. One such method, which the author mention, is pattern matching. This is about comparing patterns, for example comparing patterns found in the empirical findings with predicted patterns based on the existing theory. Patterns that match increases the validity of the result, and patterns that do not match indicates that further investigation is required. The pattern matching was used when collecting and analysing the data. Due to collecting data from different sources, it was possible to create patterns based on the information that was provided. For example, if interviews, observations, and system data point at the same occurrence, it becomes a pattern. However, if different sources provide different facts, it can be worth investigating the situation further by for example getting more data and get an understanding of the situation.

Matched patterns helped to understand the challenges and bottlenecks related to the picking process because of several sources of evidence. Furthermore, pattern matching was used when formulating solutions because patterns based on contextual factors, current state, wastes and prior theories were matched together to formulate propositions. As a result, the practical implications for the case company were of relevance. Figure 8 shows the different analytical methods used.

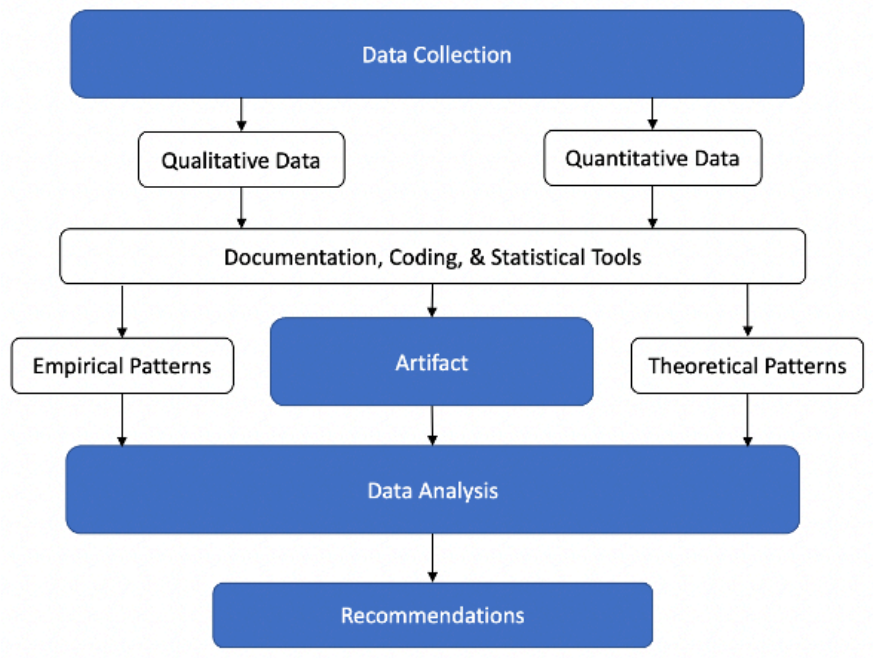


Figure 8. How the different analytical methods have been used.

2.5 Research Quality

When conducting studies, it is important with a good research design to achieve reliability and validity (Saunders, Lewis and Thornhill, 2007; Voss, Tsikriktsis and Frohlich, 2002). Saunders, Lewis and Thornhill (2007) write that reliability is about the methods for data collection and analysis, and how they produce consistent findings. They also clarify validity and that is about measuring what is intended to be measured, which affects the research findings. Thus, it is important to develop a well-designed data collection protocol to achieve reliability and validity in the study. For a case study, it is important that the data collection is rich and comes from different sources and methods (Yin, 2014). Therefore, triangulation is important to achieve reliability and validity as well. Furthermore, Yin (2014) highlights that the data collection and analysis should establish a strong chain of evidence which has been clearly documented.

Yin (2014) also emphasize that there are four commonly established tests that are used to establish the quality of social science research studies. Table 10 summarizes the definitions of these tests. Construct validity is connected to the data collection and can be achieved by using multiple sources of evidence, establishing a chain of evidence, and having key informants reviewing a draft case study report (Yin, 2014). Yin (2014) stress that internal validity is connected to the data analysis and can be achieved by doing pattern matching, explanation building, addressing rival explanations, and using logic models. Furthermore, the author writes that external validity concerns the research design and it can be achieved by using theory in single-case studies and replication logic in multiple-case studies. Lastly, reliability also concerns the data collection and can be achieved by using a case study protocol and developing a case study database.

Table 10. Reliability and validity in research, adaptation from Yin (2014).

Test	Definitions
Construct validity	The extent to which correct operational measures are used for the concepts being studied.
Internal validity	The extent to which casual relationships are established.
External validity	The extent to which the findings can be generalized.
Reliability	The extent to which the same results are given if the study was repeated.

Throughout this thesis project, these four dimensions have been considered, which is seen in Figure 9. Construct validity is reached by gathering data from interviews, observations, documents, and system data. Also, data has been confirmed through interviews and the supervisor at Tetra Pak. Opponents and the supervisor at the university have also given continuous feedback throughout the whole study. Furthermore, internal validity is created by coding the data that was gathered and identifying patterns based on sources that point at the same evidence. Thus, triangulation was key in this stage. Also, patterns were matched and compared, such as patterns from prior theories with patterns based on the empirical findings. Since the artifact was based on previous theory and the data collection is based on the artifact and therefore the frame of reference, it was possible to match theoretical and empirical patterns. Additionally, external validity is achieved by creating an artifact based on theoretical models, which can be applied at any warehouse. By applying it to one case, the study evaluates how the artifact works. However, a multiple-case study could increase the trustworthiness further because it would give a more generalizable result as it is applied to other cases and contexts. Lastly, reliability is achieved designing a research protocol to guide the collection of data. Reliability is also achieved by clearly documenting the procedure of the study throughout the whole process, to the extent that someone else can repeat it. In terms of the artifact, trustworthiness is increased by testing and evaluating it through a case study. By doing a single-case study at Tetra Pak provides great depth on how the artifact will work in practice. Also, the artifact is based on previous established theories, which creates rigor.

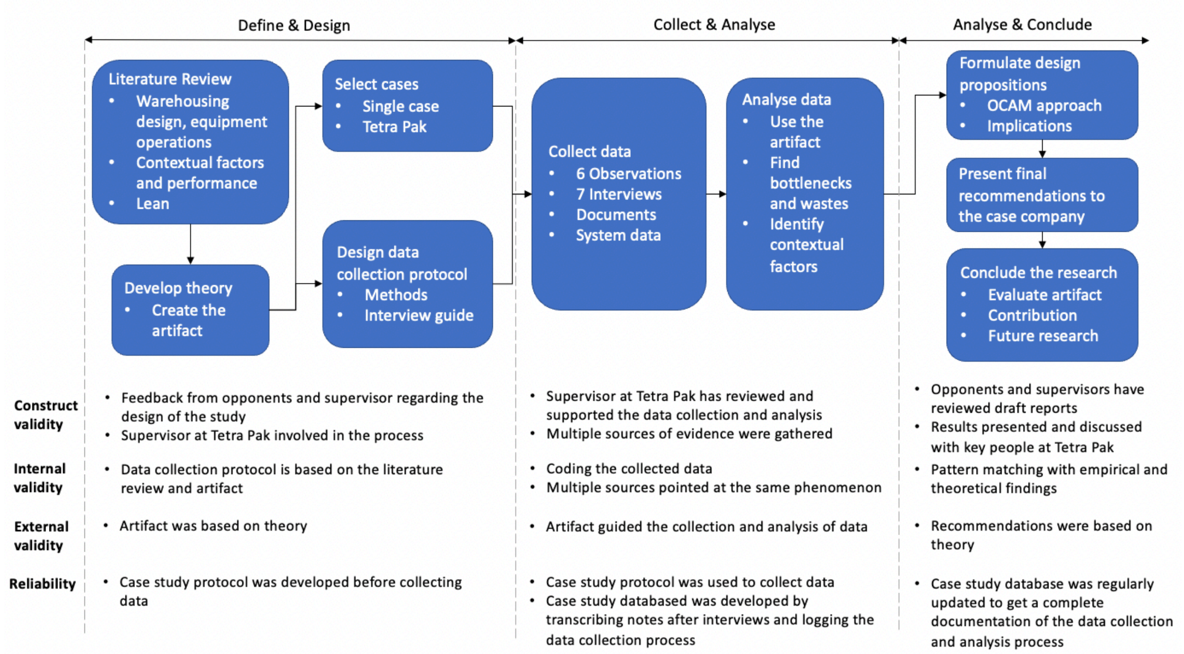


Figure 9. How trustworthiness has been increased throughout the research process (inspired by Kembro and Norrman (2019).

3. FRAME OF REFERENCE

The frame of reference includes previous theory in different areas that are necessary for the creation of the artifact. The chosen theoretical areas are related to the research topic such as warehouse design and equipment, warehousing operations, contextual factors, performance, and lean. Figure 10 shows the different subchapters in this chapter and what areas that are included in each. The first subchapter is the warehouse design and equipment, which involves physical layout, handling and storage equipment, automation, information systems and labour management. The warehouse design and equipment are basic knowledge that is required before presenting the warehouse operations. The next subchapter will present the warehouse operations that are of relevance for this report. Thus, it will start with the picking operation because of its central part in this thesis, which will be followed up by the put-away and storage operation and lastly the distribution. The two first subchapters make up the warehouse configuration, which should be adapted to the contextual factors. Thus, the third subchapter is about the contextual factors of a warehouse, where activity profiling is key to understand the context. The subchapter also includes performance because the match between the warehouse configuration and the contextual factors affects the performance. A mismatch between the two can instead result in lower performance, which can be seen as waste and bottlenecks, which is why the fifth subchapter is about lean. Lastly, the final subchapter describes the designed artifact that is based on the previous topics. The artifact can be used to improve the picking performance and will be applied at the production warehouse at Tetra Pak.

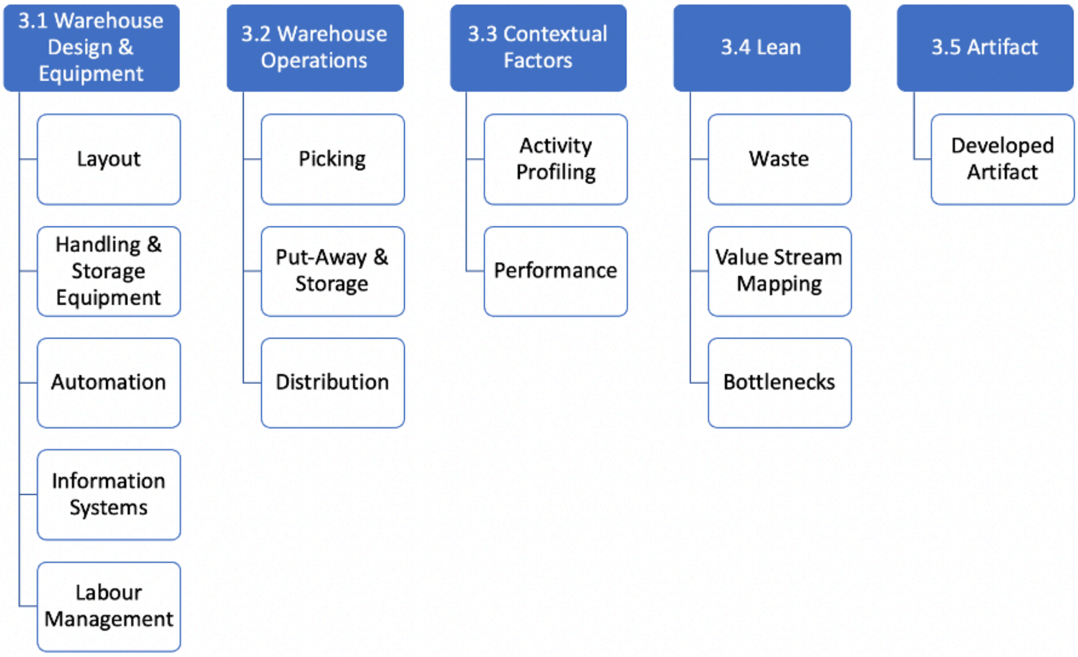


Figure 10. An overview of the different subchapters in the frame of reference chapter.

3.1 Warehouse Design & Equipment

3.1.1 Layout

The physical layout of a warehouse is important because it affects the cost related to storage locations and therefore it is important to consider the placement of receiving and shipping. Bartholdi and Hackman (2019) mention three areas to consider regarding layout, which is space, location of receiving and shipping, and aisle configuration.

According to Bartholdi and Hackman (2019), a warehouse wants to be able to store many items per unit of area because cost is related to the square-meter. This is done by using the vertical space and using deep lanes. The vertical space can be utilized by either stacking pallets on top of each other or using pallet racks. Furthermore, lane depth provides better utilization of space because the additional pallet positions can share the same aisle. However, a lane is usually dedicated to one SKU to avoid double-handling. Table 11 summarizes the different methods and their pros and cons.

Table 11. Methods to utilize the warehouse space (Bartholdi and Hackman, 2019).

Method	**Pros**	**Cons**
Floor storage	Cheap. Pallets can be stacked.	Heavy or fragile items cannot be stacked.
Racks	Uses vertical space more efficiently. Can store heavy or fragile items. Easier to store and retrieve. Safer.	Cost.
Lane depth	Additional pallet positions share the same aisle space.	Less utilization of pallet positions with deeper lanes.

Bartholdi and Hackman (2019) clarify how the physical layout, in terms of receiving and shipping, can affect the convenience of storage locations. Figure 11 shows a flow-through configuration to the left and a U-flow configuration to the right, where the dark storage locations are the most relevant. In a flow-through configuration, the most convenient storage locations are the one that are across the receiving and shipping end. In a U-flow configuration, the most convenient storage locations, are the ones that are close and in between the receiving and shipping ends. Bartholdi and Hackman (2019) also highlight that both are suitable depending on the context, which is described in Table 12.

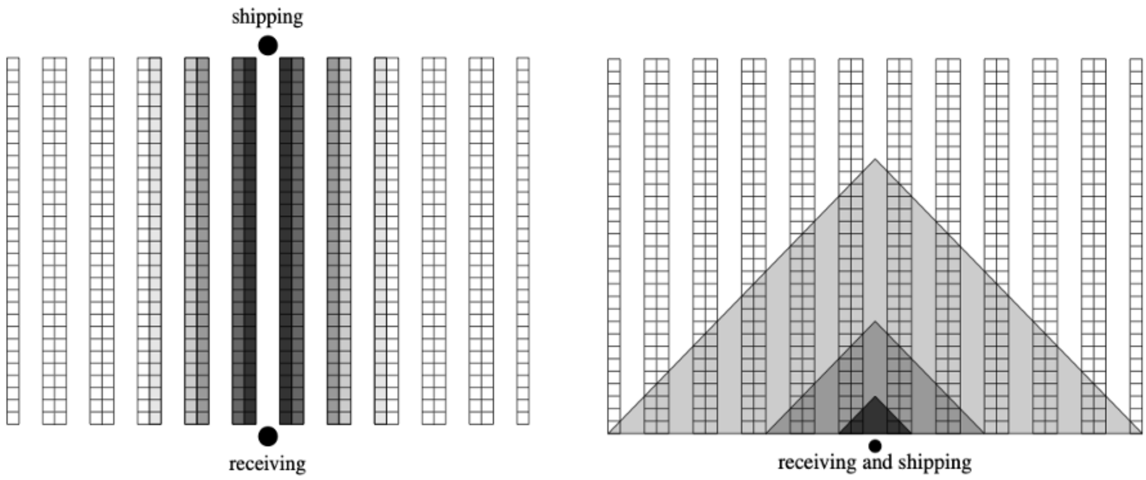


Figure 11. Flow-through configuration and U-flow configuration (Bartholdi and Hackman, 2019).

Table 12. Pros, cons, and suitable context of the configurations (Bartholdi and Hackman, 2019).

Configuration	Pros	Cons	Suitable context
Flow-through	More convenient storage locations than U-flow.	Locations are less convenient than U-flow.	The warehouse has high volumes of SKUs.
U-flow	Locations are more convenient than flow-through.	Fewer convenient locations than flow-through.	When the warehouse activity is concentrated to a few SKUs.

Aisle configuration is another important aspect of physical layout to consider. According to Bartholdi and Hackman (2019), aisles usually run parallel with the direction of the material flow to reduce traveling. It can also be beneficial to enable movement between storage locations by having a cross-aisle, seen in Figure 12, which reduces travelling between storage locations. However, this means additional costs due to the floorspace that is needed to make a cross-aisle, which also increases the traveling. The pros and cons are summarized in Table 13.

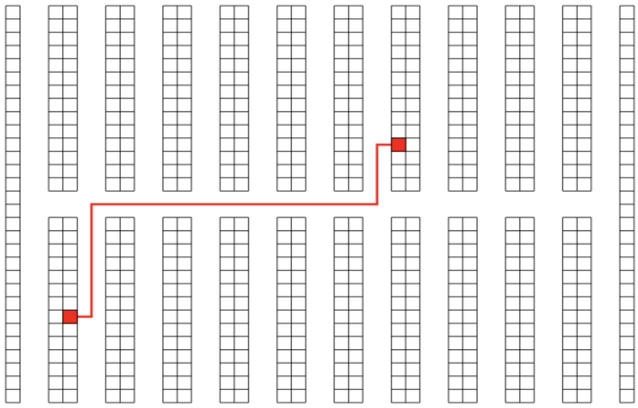


Figure 12. Aisle configuration (Bartholdi and Hackman, 2019).

Table 13. Pros and cons with different aisle configurations (Bartholdi and Hackman, 2019).

Aisles	Pros	Cons
Few aisles	Better use of space.	Traveling and congestion.
Many aisles	Less travel and congestion.	Requires space.

3.1.2 Handling & Storage Equipment

There are many kinds of storage and handling equipment that a warehouse can have, depending on the context. According to Bartholdi and Hackman (2019), they can reduce labour costs and increase space utilization, for example by storing SKUs using the height or placing many SKUs on a small area to reduce travelling. Furthermore, the authors mention that rack storage allows the possibility to access loads on each level while utilizing the height of the warehouse. Table 14 describes some of the most common types of rack storage for both pallets and cases. Bartholdi and Hackman (2019) also explain that lift trucks are usually needed to access the loads in pallet racks. Automated storage-and-retrieval systems (AS/RS) does not require a lift truck to access the loads. Table 15 summarizes the most common types of handling equipment.

Table 14. Description of different rack types (Bartholdi and Hackman, 2019).

Rack types	Description	Pros	Cons
Single-deep rack	Rack that stores pallets one deep.	Each pallet is independently accessible.	Requires relatively more aisle space.
Double-deep rack	Rack that stores pallets two deep by placing one single-deep rack behind another single-deep rack.	Requires fewer aisles to access pallets.	Less utilization and required special handling equipment. Double-handling if FIFO.
Push-back rack	Like a double-deep rack but with more pallet positions. The rack in each lane pulls out like a drawer.	Each lane is independently accessible.	Suitable for LIFO (Last-in-First-out).
Drive-In rack	Rack that allows a lift truck to drive within the rack frame to access the pallets. It enters and leaves from the same end of the aisle.	Utilizes the warehouse space.	Suitable for LIFO. Harder to store and retrieve SKUs. Less flexible.
Drive-Through rack	Rack that allows a lift truck to drive within the rack frame to access the pallets. It enters one end of the aisle and leaves from the other end.	Utilizes the warehouse space. Allows FIFO.	Harder to store and retrieve SKUs. Less flexible.
Pallet flow rack	Deep lane rack with slanted shelves and rollers, which pulls pallets to the front when the front pallet is removed. Thus, put-away and retrieving occurs from different sides of the rack.	Utilizes the warehouse space. Suitable for warehouses with high throughput. Allows FIFO.	Requires aisle space. Not suitable for high volumes of SKUs.
Static rack (shelves)	The most simple and standard shelf type. Suitable for slower-moving and/or small items.	Cheap.	Storage and retrieving are done from the same side.
Gravity flow rack (shelves)	A special type of shelving with tilted shelves and rollers to bring cases forward when the front case has been picked.	Suitable for faster-moving items. Storage and retrieving are done from different sides.	Requires aisle space. Expensive.

Table 15. Description of different handling equipment (Bartholdi and Hackman, 2019).

Lift trucks	Description
Counterbalance lift truck	The most standard and all-around lift truck. There are both a sit-down version and a stand-up version
Reach lift truck	The truck has a reach mechanism that allows its forks to extend to put-away and retrieve a pallet.
Double-reach lift truck	Like the reach lift truck but it can access the rear positions of double deep racks.
Turret truck	The truck has a turret that can turn 90 degrees, left or right, to put-away and retrieve loads.
Stacker crane within an AS/RS	the handling component of a unit-load AS/RS, which has a crane with tracks mounted to the roof or floor.

3.1.3 Automation

As warehouses require a lot of human labour, automation has been a solution for substitution. Bartholdi and Hackman (2019) underline that automation often substitutes human labour by reducing traveling related to the picking with the help of automated storage-and-retrieval devices. According to the authors, automation is only worth it if labour is relatively expensive. They also highlight that automation has disadvantages in terms of inflexibility. If the business changes it can be very expensive because they are designed to specific tasks. Three automation solutions are summarized in Table 16.

Table 16. Overview of warehouse automations (Bartholdi and Hackman, 2019).

Automation	Description
Carousel	A rotatable circuit of shelving, where the storage location travels to the picker. Suitable when having many items in shelves.
A-frames	An automated dispensing machine, where items are dropped down onto a conveyor. Suitable when labour is expensive, high volumes are picked and SKUs are small and enduring.
AS/RS	A simple robotic device within each aisle, which can move horizontally and vertically to put-away or retrieve unit-loads. Suitable when labour and space is expensive.

3.1.4 Information Systems

One of the most common information systems is an Enterprise Resource Planning Systems (ERP). Nettsträter et al. (2015) highlight that software systems, such as an ERP system, are vital for logistics processes. It is often used throughout an entire company and their functionalities have expanded over the years. An ERP system can be defined as: “a tool for comprehensive planning, coordination and management of companywide tasks” (Nettsträter et al., 2015, p.3). Thus, it efficiently coordinates all existing company resources. According to Nettsträter et al. (2015), some key functions of an ERP system involve sales, purchasing, production, demand planning, warehouse management, financial accounting, customer services, quality management, research and development, and human resources. In addition, an ERP system can have additional functionalities, such as customer relation management, supplier evaluation, inventory control, performance indicators, order schedule, and warehouse control.

The operations in the warehouse can be coordinated with the help of a Warehouse Management System (WMS). A WMS is an information system that supports inventory management, storage locations and the workforce (Bartholdi and Hackman, 2019). It contains information on every SKU and storage location in the warehouse and their physical properties and addresses, but also information on customer orders. Thus, it can control the flow of people, machines, and products to ensure efficient picking, packing, and shipping. For example, the WMS can transform customer orders to pick-lists with a sequence based on an efficient route. Bartholdi and Hackman (2019), also stress that a WMS can include many different features to allow further control, such as information on receiving or information regarding other areas in the supply chain. Similarly, Nettsträter et al. (2015) state that the scope of WMS has been larger and now offers functionalities which originate from enterprise resource planning systems, supply chain management software or transport management systems. The authors mention key functions that involves receiving, put-away, order picking, shipping, warehouse control, order release, inventory management, information systems, and master data. Some additional functions are resource planning, value added services, returns, forklift control system, batch numbers, serial numbers, and management of best before dates. Furthermore, the authors highlight that the functionalities can have add-ons for communication with the picker, for example pick-by-light, or systems which identify the products such as handheld scanners.

3.1.5 Labour Management

Labour management is important in a warehouse because they are a significant part of the warehouse costs. Since demand can change dramatically, the workload in the warehouse changes accordingly, which means that it is necessary with strategies to plan manpower in warehouses (De Leeuw and Wiers, 2015; Dewi and Septiana, 2015). Having an incorrect workforce scheduling can result in an unbalanced workload, which results in job dissatisfaction of the employees (Dewi and Septiana, 2015). Furthermore, De Leeuw and Wiers (2015) shows that manpower planning strategies have an impact on the turnover. The authors describe four different strategies, which are: flexible contracts, flexible planning, job rotation and workload balancing. Flexible contracts involve using flexible and temporary workers, meaning they have a specified end-date to their contracts. Another strategy is flexible planning, which means that employees with fixed contracts work in a flexible manner based on the contract in terms of working hours and free days. For example, the contract can state that a certain number of worked hours must have been done during a year, but the worker can distribute it flexibly throughout the year. This strategy comes with benefits such as better utilization of the personnel, shorter lead times and higher job satisfaction due to better balance in work and free time for the employees. Job rotation is the third strategy. It means to systematically shift employees between different operations. Thus, employees need to be capable of handling different warehouse operations and it results in a more varying workload for the employees. The last strategy is workload balancing, which is about planning the workload in a balanced manner by shifting the work between busy and calm days. This results in reduced overtime and idle time, as well as better job satisfaction of the employees. The different strategies are summarized in Table 17.

Table 17. Description of different manpower planning strategies (De Leeuw and Wiers, 2015).

Manpower planning strategies	**Description**
Flexible contracts	Using flexible and temporary workers, which have specified end-date to their contracts.
Flexible planning	Employees with fixed contracts works in a flexible manner based on working hours and free days, which are agreed through the contract.
Job rotation	Systematically shift employees between different operations.
Workload balancing	Planning the workload in a balanced manner by shifting the work between busy and calm days.

3.2 Warehouse Operations

Warehousing involves different operations to manage the material that goes in and out of the warehouse. Bartholdi and Hackman (2019) highlight that the goods are often received in larger batches, and they leave in smaller quantities. Thus, an important function of the warehouse is to rearrange and repackage products, which is why warehouses have different operations which aim to do so. Figure 13 shows the typical processes in a warehouse (Bartholdi and Hackman, 2019; Kembro, Norrman, and Eriksson, 2018). Receiving and put-away belongs to the inbound processes, while order-picking and distribution goes into the outbound processes. Distribution is also known as packing and shipping, but in this thesis the term distribution will be used. As the thesis focuses on picking and its closest related operations, this chapter will only discuss put-away and storage, picking, and distribution.

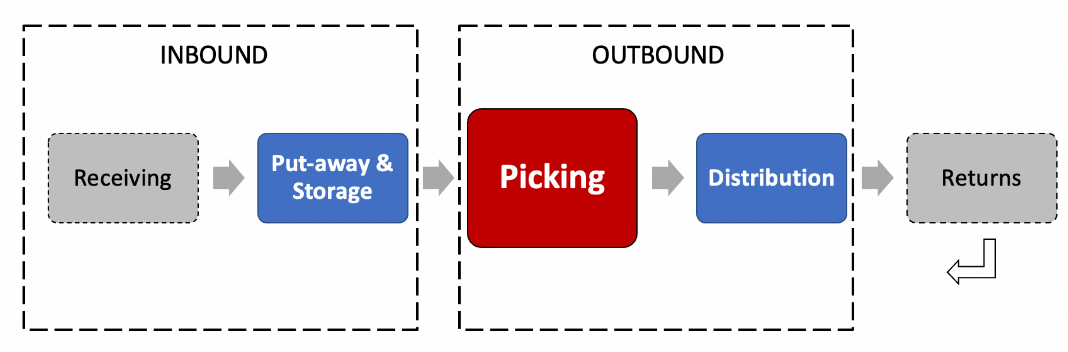


Figure 13. The warehouse operations of a warehouse, adapted from Kembro, Norrman, and Eriksson (2018) and Bartholdi and Hackman (2019).

3.2.1 Picking

Order-picking starts with a customer order with order-lines, where each line refers to an item and the desired quantity (Bartholdi and Hackman, 2019). It is necessary to confirm that available inventory exists, in order to create pick-lists, which work as instructions and guide the pickers during the picking process in an efficient manner. The authors highlight that each pick-line on the list includes a storage location, the item to be picked, the quantity and units of measure. Also, the warehouse must schedule the order-picking and shipping, as well as fix shipping documentation.

The order-picking process is often the most time-consuming warehouse activity and accounts for the main part of warehouse operating expenses (Bartholdi and Hackman, 2019; Bottani et al., 2012; Le-Duc and De Koster, 2005). Especially, if there are smaller handling units because they mean greater handling cost. The picking of less-than-carton quantities, also called broken-case picking, is most labour-intensive. Bartholdi and Hackman (2019) emphasize that the order-picking process can be broken down to the following activities: traveling, searching, extracting, and paperwork and other activities. The authors stress that traveling usually is the activity that takes most time, therefore it is the most expensive part of the operating expenses. Thus, it is desired to minimize the traveling in the order-picking process, which can be done by making pick-lists which only focus on a particular part of the warehouse. Since traveling represents the largest labour cost, the number of pick-lines indicates the labour requirement.

Another activity related to the order-picking process is replenishment and this typically involves larger units of measure, therefore it is not necessary to have equally many restockers as pickers (Bartholdi and Hackman, 2019). Often it is enough with one restocker to every five pickers, but it depends on the context and material flow.

Bartholdi and Hackman (2019) explain that order-picking is associated with informal measures, such as SKU density and pick density. SKU density is the number of SKUs per unit of area on the surface of where SKUs are picked. If the SKU density is high, the number of picks per unit of area on the surface, called pick density, is high as well. A high pick density would require less travel per pick and therefore the goal is to increase the pick density. This can be achieved by placing the SKUs that are frequently picked in the most convenient places or place SKUs that often are picked together close to each other (Bartholdi and Hackman, 2019; Gu, Goetschalckx and McGinnis, 2007).

It is also important to select the appropriate picking method to improve the picking efficiency (Kembro, Norrman, Eriksson, 2018). According to Gu, Goetschalckx and McGinnis (2007), order-picking involves decision about batching, routing, and sequencing, and sorting. Four common order-picking methods are single, batch, zone, and wave (Bartholdi and Hackman, 2019), but there are also mixes between them. Table 18 summarizes the order-picking methods.

Table 18. Overview of the different order picking methods (Bartholdi and Hackman, 2019; Gu, Goetschalckx and McGinnis, 2007; Petersen, 2000).

Order-picking method	**Description**	**Pros**	**Cons**
Single picking	One order at a time. Suitable for larger order.	Order integrity and avoids double handling. Handled by one picker, no coordination needed. Does not need consolidation. Fast service.	More traveling. Not possible to speed pick large quantities of the same SKU.
Batch picking	Several orders at a time. Suitable for smaller orders but it can also be beneficial for very large orders with small items.	Less traveling.	Order integrity is lost. Risk for more errors. Requires sorting.
Zone picking	Pickers should pick from their assigned zone. Suitable when shared workload is needed due to large orders, picking from different areas or time constraint.	Less traveling and congestion. Familiarity with items in zone and more accountability.	Requires consolidation. Requires more planning.
Sequential zone picking	An order moves from zone to zone to be complete. Suitable when shared workload is needed due to large orders, picking from different areas or time constraint. Also, when order integrity is wanted.	Order integrity, no sorting required. Less traveling and congestion. Familiarity with items in zone and more accountability.	Delays and imbalances in workloads. Can cause starvation or blocking of work. Requires more planning.
Batch zone picking	Batched orders with pickers picking from their zones. Suitable when shared workload is needed due to large orders, picking from different areas or time constraint. Also, when orders are small.	Less traveling and congestion. Familiarity with items in zone and more accountability. Allows volume picking of items.	Order integrity is lost. Risk for more errors. Requires sorting. Requires more planning.
Wave picking	Batch zone picking based on time. Suitable when wanting greater volume picking than batch zone picking.	Less traveling and congestion. Familiarity with items in zone and more accountability. Allows volume picking of items.	Order integrity is lost. Risk for more errors. Requires sorting. Requires more planning.

Single picking is when each order-picker picks one order at a time, while batch picking is when each order-picker picks several orders in one trip (Petersen, 2002). Bartholdi and Hackman (2019) highlight that the downside with batch picking is that it requires sorting into orders sometime in the process, which involves time, space, and increased risk of errors. Often it is beneficial to batch single-line orders or large orders with small SKUs, while very large orders often have quite high pick density and so they typically do not need to be batched. Furthermore, zone picking is when the warehouse is divided into zones and order-pickers should only pick in their assigned zone (Bartholdi and Hackman, 2019). Sequential zone picking is when an order is passed between zones and in each zone, the worker picks the pick-lines that belongs to their zone (Petersen, 2000). Petersen (2000) also mention batch zone picking, which is a mix between batch picking and zone picking. This means that orders are batched together, and workers pick items from their zone. Lastly, there is wave picking, which is a special kind of batch zone picking based on time, where wave lengths often vary between 30 minutes to 2 hours (Petersen, 2000).

Another decision related to the picking is if the customer order should be picked by one worker or by many workers at the same time. According to Bartholdi and Hackman (2019), it is called serial when a single worker picks an order and parallel when several workers pick for the same order. The authors highlight that there are many factors that can affect the choice of this picking strategy, but the most important factor to consider is response-time, meaning how quickly do orders need to be completed. By picking in parallel, orders may be completed faster, but multiple pickers need to be coordinated and the different parts of the orders must be consolidated.

Travel can also be reduced through routing, which means to optimize the pick path in the warehouse to minimize the traveling (Bartholdi and Hackman, 2019). Petersen (1997) evaluates six routing strategies: transversal, return, midpoint, largest gap, composite, and optimal. Figure 14 shows the heuristic policies, and the letter "p" represents a picking location.

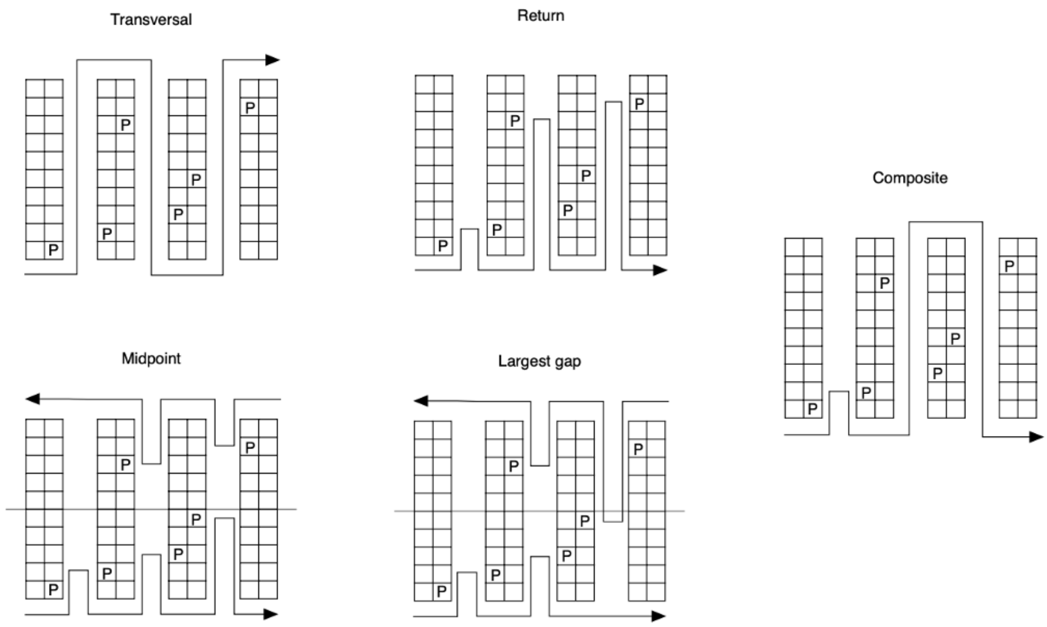


Figure 14. Order picking routing strategies (Petersen, 1997).

According to Petersen (1997), the transversal policy is the simplest of them, where the order-picker travels through each aisle that contains a pick. The return strategy is similar, but instead the picker leaves at the same end of the aisle as where the picker entered. The midpoint policy means that the warehouse is broken down into two sections and a picker cannot go further than the midpoint and then must return. The largest gap strategy is more complicated, but similar to the midpoint strategy. The picker cannot go beyond the largest gap within an aisle, instead of a midpoint. The gap refers to the largest distance between any two adjacent picks, between the first pick and the front aisle or the last pick and the back aisle. Thus, if the largest gap is between two adjacent picks, it means that the order-picker does a return route from both the front and back aisle. Otherwise, the picker does a return route either from the front or back aisle. The routing policy, composite strategy, is a combination of the return and transversal strategies and minimizes the travelling between the farthest picks in two adjacent aisles. Lastly, the optimal routing uses an optimal algorithm with the help of a computer to get the optimal route. Petersen and Aase (2004) highlight that switching from transversal to optimal routing reduces travel, but it is significantly less than changing storing picking or storing policies. They also highlight that simple routing heuristics are more acceptable because the routes are consistent compared to optimal routes, which can cause confusion and increase time and error. Table 19 summarizes the pros and cons of the different routing strategies.

Table 19. Pros and cons for the different strategies (Petersen, 1997; Petersen and Aase, 2004).

Routing Strategy	**Pros**	**Cons**
Transversal	Easiest to use. When pick-lists are large.	More traveling.
Return	Easy to use.	Most inefficient method.
Midpoint	When pick-lists are small.	
Largest Gap	When pick-lists are small. Close to optimal routing.	
Composite	Close to optimal routing. When pick-lists are large.	
Optimal	Best solution.	Requires optimization model and can cause confusion.

3.2.2 Put-Away & Storage

The put-away process starts with deciding where to store the product (Bartholdi and Hackman, 2019). The location is important because it affects how quickly you can retrieve it and thus it is necessary to manage storage locations. According to Bartholdi and Hackman (2019), this can be seen as another type of inventory, where storage locations are the products and it is necessary to track if there are storage locations available, the sizes of them and the maximum weight they can handle. The authors explain that after the location has been selected, the product is put away and when doing so the location is scanned to confirm the product's placement. The labour requirement can be relatively high due to long transportation distances in the warehouse.

There are different storage policies to consider for achieving efficiency, which are summarized in Table 20. Each storage location is often categorized as dedicated or shared (Bartholdi and

Hackman, 2019). Dedicated means that each location is reserved for an assigned SKU, which means that only that SKU is allowed to be stored at that location. This is useful for storing popular SKUs at convenient locations because it makes picking easier for workers due to SKUs having the same picking locations. Thus, picking becomes more efficient. However, dedicated storage does not use space efficiently because the inventory is on average half empty. Bartholdi and Hackman (2019) also explain shared storage, which is that each storage location is not dedicated to a certain SKU. Thus, when a location becomes empty, another product can be stored there. It can be filled quickly again, instead of waiting for replenishment of the previous product. This results in better space utilization.

Table 20. Overview of different storage policies (Bartholdi and Hackman, 2019; Gu, Goetschalckx and McGinnis, 2007; Petersen, 2002; Petersen and Aase, 2004).

Storage policies	**Description**	**Pros**	**Cons**
Shared storage	SKUs are placed randomly. Suitable when an order has many pick-lines.	Easy and flexible. Better space utilization. Less congestion.	Increased traveling. Requires WMS. Cannot learn where items are stored. Many possible trade-offs.
Dedicated storage	SKUs are placed at reserved locations. Suitable for popular SKUs.	Less traveling. Workers learn where the items are.	Space is not used efficiently.
Class-based storage	SKUs are placed within a warehouse zone that it belongs to. Suitable when products can be categorized.	Less traveling, while flexible. Better space utilization. Easier to use than VBS.	Risk of congestion, however less risk if popular SKUs are stored in several classes.
Volume-based storage	SKUs with high demand are placed in the most convenient locations. Suitable for popular SKUs.	Less traveling. Popular SKUs in most convenient locations. Workers learn where the items are.	Space is not used efficiently. Requires more planning. Risk of congestion.
Family grouping	SKUs that are picked together are placed close to each other. Suitable for related SKUs.	Less traveling. Better space utilization. Workers learn where the items are.	Requires more planning. Space is not used efficiently.
Forward picking area	Smaller amounts of fast-moving SKUs are placed within a small area, which is replenished from a reserve. Suitable for popular orders that are less than pallet-loads.	Less traveling. Popular SKUs in most convenient locations.	Requires more planning and space. Requires more replenishment.

According to Gu, Goetschalckx and McGinnis (2007), class-based storage is another storage policy where the warehouse is divided into zones. SKUs are then classified and stored according to what zone they belong to, which is often based on pick frequency. This can be seen as a mix between dedicated and shared storage locations, as SKUs are dedicated to a certain zone, but a zone can have a shared storage policy. This results in shorter traveling and better utilization of space. However, it is possible for a zone to follow a dedicated storage policy (Gu, Goetschalckx and McGinnis, 2007). Furthermore, Petersen and Aase (2004) highlight volume-based storage policies, which means that SKUs with the largest demand are placed in the most convenient locations, that is the locations that are closest to the inbound and outbound. The authors conclude that a simple class-based storage policy can almost achieve the same benefits as a much more information intensive volume-based storage policy.

Another policy is to store SKUs by family. Bartholdi and Hackman (2019) state that related SKUs that must be stored together are called a product family. They also highlight that this strategy can result in better space utilization because products that have similar sizes or shapes can be stored together. In addition, put-away can be simplified if SKUs are placed based on vendor because they usually arrive in the same truck and are then placed in the same warehouse area.

A fast-pick area is another policy that can be used to store and pick pieces. Bartholdi and Hackman (2019) describe this as a separate picking area in the warehouse where picking occurs within a relatively small area. Often SKUs that are frequently demanded are put there in small quantities. Thus, travelling is reduced. However, it may require replenishment from bulk storage.

3.2.3 Distribution

The last activities on the outbound are checking, packing, and shipping (Bartholdi and Hackman, 2019). Packing is usually quite labour-intensive because it handles each piece of the order and checking can be done while packing. It is important to get the orders right, otherwise it ends up as a return and they are expensive to handle. Another important factor to consider is that customers usually want their orders in the same container, which may require more handling. When the checking and packing is done, it is time to ship the order to the customer. The labour requirement is quite low because the units are often larger than picking since packing has consolidated the items into a container.

3.3 Contextual Factors

The previous two chapters show that warehouse configuration includes many decisions that are interrelated and complex. In addition, the environmental context needs to be considered in every situation and for warehousing that means the operating environment, which is hard to influence in short term (Faber, de Koster and Smidts, 2013). According to Kembro and Norrman (2020), it is important to understand the context in which the warehouse operates in because various contextual factors need to be considered when designing the warehouse configuration, meaning the warehouse operations, design, and resources.

One important contextual factor to consider is the purpose of the warehouse (Kembro, Norrman and Eriksson, 2018). Bartholdi and Hackman (2019) highlight that a warehouse is a place where it is possible to store products, but also reorganize, repackage, and consolidate products. It all depends on the purpose of the warehouse. For example, it can be to meet demand better, shorten lead times, improve customer service, or lower cost. The authors also highlight the possibility to postpone product differentiation and value-adding activities, for example pricing, labelling, and kitting. Furthermore, Rouwenhorst et al (2000) distinguishes between a distribution warehouse and a production warehouse. The authors state that the purpose of a distribution warehouse is to act as a storage location and handle external customer orders, often orders with many products. The goal with these warehouses is to make the order picking process cost-efficient due to many different SKUs and low quantities per order line, where order line refers to a particular product on an order and its desired quantity. Thus, the overall goal is to maximize throughput at a minimum cost. Rouwenhorst et al (2000) also highlight that a production warehouse functions as a storage for stock related to the production process, such as raw materials and work-in process and finished products. Often it is necessary to store the goods for a longer period because batches that are procured are larger than the produced batches or that produces batches are larger than the quantity of the customer order. Therefore, the aim of a production warehouse is to have high storage capacity and low investment and operational costs. However, work-in-process often has unpredictable demand and needs to be retrieved fast from the warehouse to avoid production delays. This means that production warehouses also need to consider the time between an order request and its completion, in other words the response time. Even though there are differences between a distribution warehouse and a production warehouse, all types of warehouses usually receive bulk shipments and store them into the warehouse and then when a customer order arrives, they retrieve, sort, and check the products, package the order, and ship it away (Bartholdi and Hackman, 2019).

The purpose of the warehouse is an important contextual factor because it can give an indication on other contextual factors of a warehouse. Other factors include customer characteristics, demand profile, order characteristics, assortment, volume, product characteristics, and process characteristics (Faber, de Koster and Smidts, 2013; Kembro and Norrman, 2020; Kembro, Norrman and Eriksson, 2018). For example, a production warehouse tells that the customer to some extent is the production and that product characteristics can include raw material, work-in-process, and finished goods. Table 21 gives an overview of different contextual factors.

Table 21. Examples of contextual factors in warehousing, based on Faber, de Koster and Smidts (2013), Kembro, Norrman and Eriksson (2018), and Kembro and Norrman (2020).

Contextual Factor	**Description**	**Influences**
Customer characteristics	The number and types of customers.	Assortment
Demand profile	Seasonality of demand.	Storage and labour requirement
Product characteristics	The type of SKUs stored in the warehouse and if they require special requirements in terms of service or handling.	Handling and storage equipment required
Assortment	Number of SKUs in the warehouse and the introduction of new SKUs.	Storage requirement
Volume	Warehouse throughput and popular SKUs.	Picking process
Order characteristics	Number of orders, number of pick-lines per order, and number of units per pick-line.	Picking process
Process characteristics	Characteristics of the warehouse processes, such as picking, put-away and distribution.	Picking process

3.3.1 Activity Profiling

A warehouse is a complex matter with many operations and flows, and by understanding the activities in the warehouse, one can recognise the contextual factors that influences the warehouse. Bartholdi and Hackman (2019) mention *warehouse activity profiling* as a measurement and statistical analysis tool for understanding the warehouse activity. There are some key facts to learn about a warehouse, which are summarized in Table 22. The authors emphasize that it gives an overall understanding of the warehouse context.

According to Bartholdi and Hackman (2019), calculating averages can be a useful way to understand the economics of the warehouse, however it is important to be aware of simple averages that can give a misrepresentative picture. They also mention that the main data that is needed to understand the activities are: SKU data, customer order history, and data on the physical layout. The authors state that the customer orders and pick-lines, indicates work and transportation. Thus, by studying the activity of each SKU, it gives an understanding of where and when work occurs.

Table 22. Key measures for activity profiling, adapted from Bartholdi and Hackman (2019).

Area	**Key facts**
Demand	The type of business/warehouse and its customers. Special requirements in terms of service or handling. Seasonality.
Layout	Area of the warehouse. Types of storage. Material handling equipment. Space utilization.
SKUs	Average number of SKUs in the warehouse. Average rate of introduction of new SKUs. SKU popularity distribution.
Picking	Average number of pick-lines shipped per day. Average number of units per pick-line. Number of order-pickers.
Inbound	Average number of shipments received in a day.
Outbound	Average number of customer orders shipped in a day.

3.3.2 Performance

The earlier parts of the frame of reference have discussed the importance of fitting the warehouse configuration to the contextual factors of a warehouse. According to Donaldson (2001), organizational decisions that are aligned with the contextual factors results in higher performance and a misalignment would mean loss of performance, which is known as the contingency approach. This also means that if the contextual factors change, new organizational characteristics might be needed to avoid lower performance. The contingency approach in warehousing theory has gotten more attention as it focuses on fitting the warehouse configuration to the contextual factors to improve performance (Faber, de Koster and Smidts, 2017; Kembro, Norrman and Eriksson, 2018). Thus, a mismatch between the context and configuration contributes to lower warehouse performance (Kembro and Norrman, 2020; Kembro, Norrman and Eriksson, 2018).

The study from Kembro and Norrman (2020) shows that contextual factors influence the warehouse configuration since they create challenges in terms of trade-offs between different configurational decisions. For example, decisions about storage, processes, and resources and how to combine them. According to Rouwenhorst et al. (2000), the product characteristics affects how products are handled and stored, which influences the decision about handling and storage equipment. The size or weight can limit which storage equipment that can be used, and in the extreme cases they must be stored on the floor. This means that the height of the warehouse cannot be used, for example through pallets racks, which would mean more storage locations. Naturally, this affects warehouse performance. Thus, to improve performance, it is necessary to understand the contextual factors to align configurations, but it is also important to be aware of the potential trade-offs.

Furthermore, it is important to measure the performance of the warehouse. According to Bartholdi and Hackman (2019), many warehouses use key performance indicators (KPIs), which are different measures used for determining the performance of the warehouse. Some examples are response time, operating costs, operating productivity, and order accuracy. The authors mean that constant measurement of productivity is needed to improve the warehouse. However, it is not a simple task because it can be hard to know what KPIs to use and especially how to measure them in an unbiased manner. For example, pick-lines per labour hour is biased because it depends on the type of unit.

3.4 Lean

Lean is often associated with Japanese manufacturers, especially Toyota, after World War II, who applied philosophies, concepts, and tools that focused on continuous elimination of waste (King, 2019). According to Leksic, Stefanic and Veza (2020), lean is about striving towards perfection, which is done by incremental improvements in terms of eliminating waste. They highlight that lean involves many different tools for reducing and eliminating waste, where some of the important ones are 5S, Bottleneck Analysis, Value Stream Mapping (VSM), Jidoka, Just-In-Time, Kaizen and Key Performance Indicators (KPIs). King (2019) highlights both kaizen, which is continuous improvements, and elimination of all waste as the essence of lean. He also mentions Just-In-Time and jidoka. JIT is about producing at an equal rate to the demand, just in time when the customers want it. Jidoka focuses on the quality by stopping the production when defects arise and starting it again when the causes have been found and corrected.

Lean practices in warehousing have started to get more attention because the need to achieve better supply chain performance has forced warehouses to reduce unnecessary activities (De Leeuw and Wiers, 2015; Faber, de Koster and Smidts, 2017). According to Abushaikha, Salhieh, and Towers (2018), lean warehousing is about optimizing the warehouse resources and activities by reducing or eliminating wastes in the warehouse. Applying lean principles in a warehouse result in improved warehouse performance and the performance of the organization (Anđelković et al., 2017).

The material flow has a key role in supply chain management, especially in warehousing, but also in lean. The material flow can be explained as the products that move through the supply chain, where the supply chain is the sequence of processes that the product flows through (Bartholdi and Hackman, 2019). According to Childerhouse and Towill (2003) the key to supply chain integration, meaning a fully integrated and effective supply chain, is a simplified material flow. They state that the principle has acquired many names over the years, many which are connected to lean principles such as JIT or value stream management. Furthermore, Bartholdi and Hackman (2019) use fluid flow as a metaphor for material flow, which provides some useful insights. Based on fluid dynamics, the authors mean that the flow of product will go slower in wider pipe segments, meaning sequences in the supply chain with large inventory. Similarly, the material flow will go faster where the inventory is little, see Figure 15. Thus, by reducing the diameter of the pipe, which means reducing inventory, products will move faster.

This will reduce lead time and in-transit inventory, which the authors highlight is aligned with just-in-time logistics. However, the metaphor also indicates that warehouses should have a continuous material flow and avoid stops because it requires extra handling and space, as well as avoiding a warehouse design which hinders smooth flow. Double-handling refers to the act of stopping a product and the need to pick it up again later. The fluid-flow metaphor can also be used to identify and manage bottlenecks to obtain a good flow.

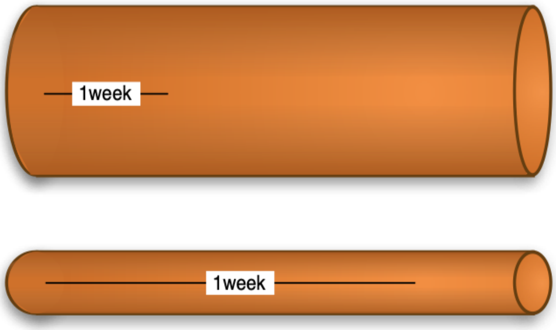


Figure 15. The material flow metaphor (Bartholdi and Hackman, 2019).

3.4.1 Waste

The continuous elimination of waste is a fundamental part of lean and to eliminate waste, it is necessary to identify waste and understand value. Waste is defined as "anything that consumes resources (people, material, time) without creating value" (King, 2019, p.39). Thus, it is important to understand what the customers value as the first lean principle states. When the value is clear, it is possible to identify and eliminate waste. Furthermore, the study from Abushaikha, Salhieh, and Towers (2018) shows that a reduction of waste levels, results in better warehouse operational performance and distribution performance. There are several different categories of waste, where the most important ones are summarized in Table 23.

Even though there are many wastes, some wastes are necessary and hard to eliminate. King (2019) distinguishes between necessary and unnecessary waste. Necessary waste, such as transportation within a plant and some inventory, is needed to have a smooth and continuous flow. They are still waste and should not be ignored, but it is important to be aware that they are difficult to eliminate. In opposite, unnecessary waste does not contribute to maintaining a smooth flow or ensuring delivery to customers. It does not fulfil any purpose and are no longer required. Often it is easier to remove because it only requires commitment, rather than performance improvement, which is needed for necessary waste. Also, King (2019) emphasize that necessary waste can become unnecessary after process improvements. Thus, it is important to continue investigating the wastes.

Table 23. Description of the seven wastes, based on Abushaikha, Salhieh and Towers (2018), King (2019), Abhishek and Pratap (2020), and Leksic, Stefanic and Veza (2020).

Waste	Waste in warehousing
Overproduction	Picking or preparing orders before there are demand for it downstream. This can cause congestion.
Waiting	Waiting due to unavailability of products, machines, or the system. Also involves stoppage of inventory movement.
Transportation	Unnecessary movement of products, workers, and forklift operators. This waste can occur if SKUs are not stored in a logical manner, as it means longer searching times.
Over processing	Unnecessary actions or activities. For example, re-entering certain information, such as scanning multiple barcodes, and inspection or packing that is not necessary.
Inventory	Involves excessive amounts of inventory, such as storing safety or buffer stock in the warehouse.
Motion	When materials are not stored ergonomically, and workers must reach or bend over to pick the items. This is also true for put-away. Also, involves searching for equipment.
Defects	Pick errors that involve the wrong item or quantity. Results in returns.

3.4.2 Value Stream Mapping

Value stream mapping is a key lean tool for managing waste and improving warehouse performance. According to Garcia (2013), VSM is a first step towards lean warehousing. It is an effective tool for identifying and reducing or eliminating waste in a warehouse and can reduce lead times while improving inventory and order processing accuracy (Abhishek and Pratap, 2020; Garcia, 2003). VSM is a framework that visually represents the process by depicting the material flow and where value is created (King, 2019; Langstrand, 2016; Rother and Shook, 1999). Thus, it helps to understand where the sources of waste are in the process and what might be improved to reduce or eliminate it. According to King (2019), it provides an understanding of the entire process and its flow, inventory, wastes, and bottlenecks.

The tool also involves a future state VSM to show what the value stream would look like after lean improvements have been made (King, 2019; Langstrand, 2016; Rother and Shook, 1999). King (2019) highlights that it is a flexible tool which can be adapted to the situation. For example, parameters that are going to be used for each process step can vary depending on what is relevant and not.

A value stream map often includes the material flow and the key process steps that it flows through, along with data related to flow, quality, lead time, and throughput capability relative to takt (King, 2019; Langstrand, 2016; Rother and Shook, 1999). Takt can be defined as: "the time interval at which each item, each part, subassembly, or finished assembly must be produced to exactly meet customer demand" (King, 2019, p.12). However, takt is often expressed as a rate. The visual representation can also include how information flows is processed to manage, control, or influence the physical material flow. Furthermore, it can include a timeline, which illustrates the waste by showing value-add (VA) time and non-value-add time (King, 2019; Langstrand, 2016; Rother and Shook, 1999). To visualise these elements, there are different process icons and data boxes (King, 2019). Process icons are used to represent each major process step in the flow. Data boxes are used to display important numerical information to understand the material flow. According to King (2019), reasonable approximations can be enough and varying values can be listed by its range. Figure 16 illustrates the different icons and an example of a VSM with data boxes is found in Appendix B.

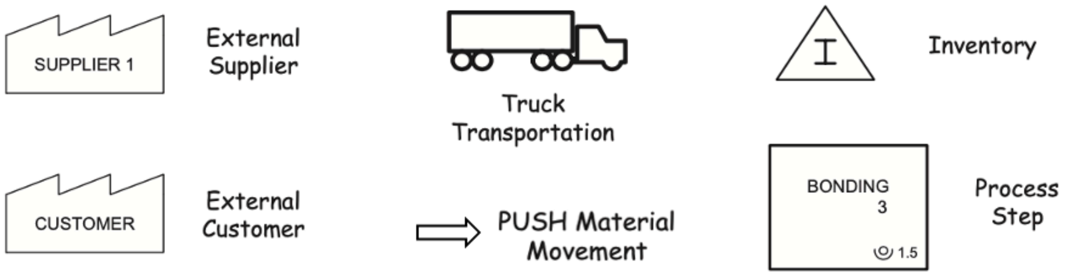


Figure 16. VSM icons (King, 2019).

The process of VSM is summarized in Table 24. King (2019) highlights that when doing the first step, it is important to learn about the general process and create a preliminary VSM. Observation of the process and interactions with the workers is key to understand the process. Furthermore, it should be a high-level view of the process, which illustrates the flow, its limitations, and the key root causes of the poor flow (King, 2019). In addition, King (2019) emphasizes that it is often recommended to select product families, rather than the full range of products because the data collection and mapping becomes easier. However, the author stresses that when all product families share the same assets, analysing product families can create a misleading picture of the material flow. It can hide information on bottlenecks because it does not represent how utilized assets really are. Thus, it is important to map the flow of a single product family when suitable and the entire flow where assets are shared between all products.

Table 24. The process of value stream mapping, based on Rother and Shook (1999), Langstrand (2016), and King (2019).

Step	**Description**
Step 1: Generate the current state map	Create an outline of the process by identifying the operations and external sources, such as customer and suppliers. Draw how the materials flow through the processes and where materials are stored.
Step 2: Add process data	Add process data to the current state map. Only data that is of relevance should be used, which depends on the situation and analysis.
Step 3: Add timeline and data	Calculate necessary time data for each process step and add to the VSM, along with a timeline.
Step 4: Analyse the current state map	Analyse the current state map by looking at capacity and demand. Try to understand how the process performs and where there are bottlenecks and wastes. See Table 25 for different analytical views.
Step 5: Create a future state map	By analysing the current state map, it is possible to find areas of improvement. The future state map should visualise how the process would look like after the improvements. It can generate even better ideas for improvement and help to avoid mistakes.

By analysing the current state map, you get information about the process, how it performs, and an indication of areas of improvement by reducing waste (King, 2019). Thus, it gives suggestions on how an ideal future state would look. Table 25 gives an overview of different views that a current state map can be analysed from.

Table 25. The views that a current state map can be analysed from (King, 2019).

Views	Definition
Customer	This includes parameters such as service level, quality, and delivery performance
Waste	This means looking for wastes in the process.
Non-Value-Adding Activities	This can be regarded as wastes, but it includes tasks and activities that are non-value-adding, which do not fit any of the waste categories.
Flow and Bottlenecks	Look for areas where continuous flow is lacking or reasons for why the takt rate is not reached.
Variability	This means looking for variability in the process, such as variability in supply lead time.

3.4.3 Bottlenecks

To achieve a continuous material flow through the process, it is necessary to identify, manage and improve bottleneck resources. According to Langstrand (2016), any capacity improvement must be aimed at the bottleneck because an overall process cannot work faster than its slowest operation. Thus, there is no point of improving the capacity of a non-bottleneck because it will not affect the overall capacity of the system.

A bottleneck can be defined as: "any resource whose capacity is less than or equal to the planned throughput, any machine or process step where the takt rate equals or exceeds capacity" (King, 2019, p.175). King (2019) explains that bottlenecks can look different depending on the context. In some industries, throughput is limited by people, which means that bottleneck management is about managing operating labour by appropriate staffing and task levelling. In other industries, it is the equipment that limits the throughput. The latter is harder to manage because it cannot be resolved by additional labour, overtime, or extra shifts, assuming the equipment is operating around-the-clock. The author also stresses that different material flows of product families can have bottlenecks at different locations, called moving bottlenecks.

King (2019) states that it is important to understand why the step is a bottleneck to manage the bottleneck. According to the author, the most common reasons for bottlenecks are capacity limitations of the equipment, long changeovers, mechanical reliability problems, yield losses and inappropriate scheduling. When the root cause has been diagnosed, it is possible to do improvements to resolve the bottleneck. The author explains the strategy, which begins with making sure that the bottleneck runs at maximum capacity and there are no unnecessary tasks. Secondly, adapt other processes to the bottlenecks, which means that the bottleneck throughput should be maximized by adapting the upstream and downstream processes. Lastly, try to increase the capacity of the bottleneck.

3.5 Artifact

The developed artifact that is used on the warehouse of the case company is seen in Figure 17. It supports the data collection, data analysis and development of suggestions for improvements. The artifact is divided into two levels, where the first level refers to current state of the warehouse and therefore connected to the data collection. The current state involves the configurational elements of a warehouse, which are the warehouse design, equipment, and operations. These were presented in the subchapters 3.1 and 3.2 in the frame of reference. These will help to understand the processes of the warehouse, as well as the capacities and constraints of the warehouse. The current state also involves doing an activity profile, meaning to identify the different activities in the warehouse, which is useful for understanding the context of the warehouse. Table 22 includes different key measures that can be included in an activity profile.

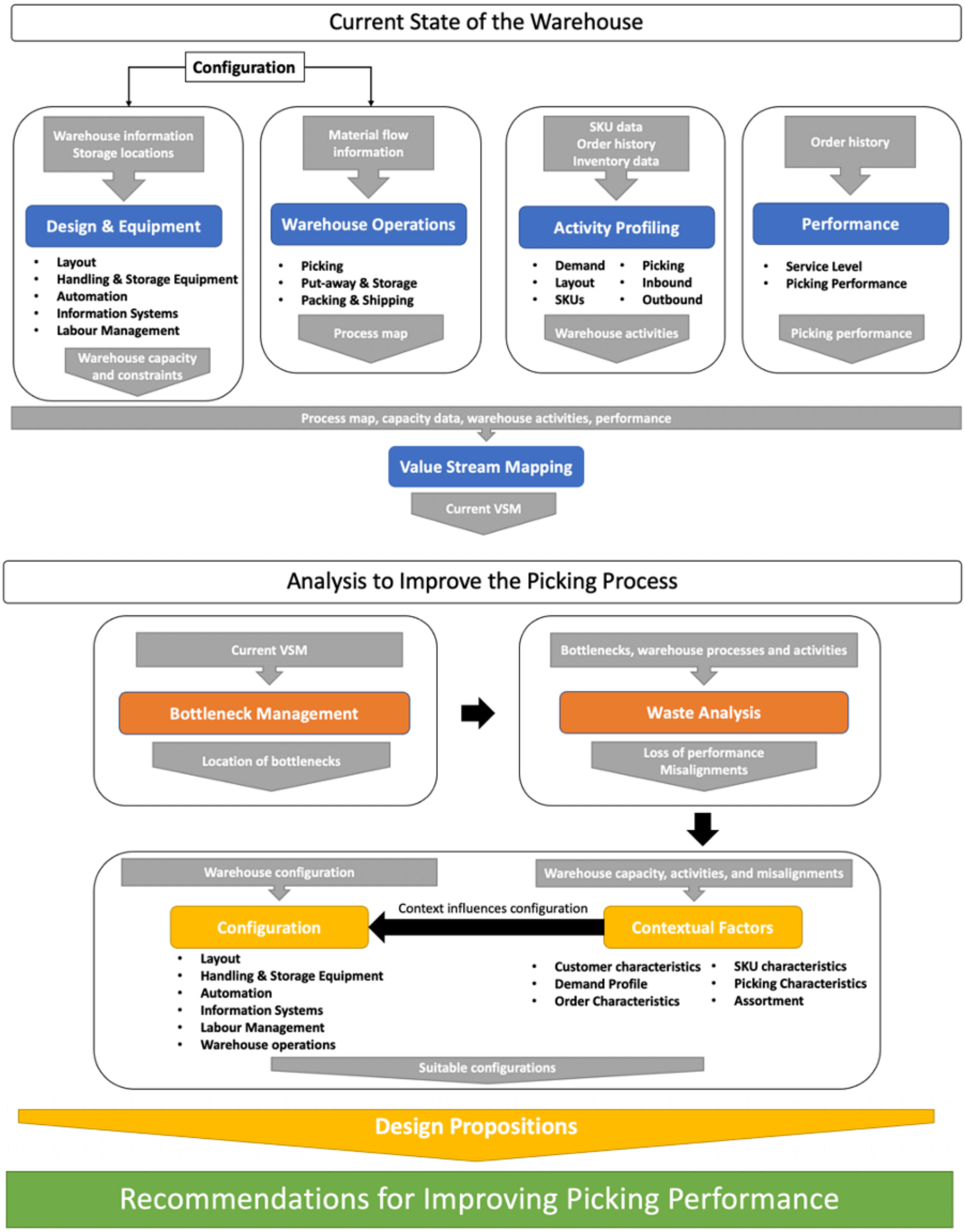


Figure 17. The created artifact based on prior theories.

Furthermore, the current state of the warehouse includes understanding the performance in terms of how the current warehouse and its picking process is operating. The performance was described in subchapter 3.3 that describes the contextual factors because performance is related to aligning configuration with the context. The data collected from this can be summarized with the help of a current value stream map to get an overview of the current situation. The process for doing a value stream map is described in Table 24, but as the VSM is a flexible tool it can look different depending on what is important. By doing a VSM based on the collected data, it is possible to get an understanding of the current state of the warehouse that will be analysed.

The next level is the analysis, which involves different theories that should be used to improve the picking process of the current warehouse. It starts off with the lean principles, where the current state of the warehouse is analysed to find bottlenecks in the material flow. The current VSM will be a helpful tool to do that as it gives an overview of the situation, which was described in subchapter 3.4. A warehouse can also have different types of bottlenecks because of their use of labour, equipment, and automation. After identifying the bottlenecks, the wastes related to them should be identified. Table 23 presents the seven wastes that a warehouse can have. The wastes are important because the first step of managing bottlenecks is to make sure that the bottlenecks run at maximum capacity and there are no unnecessary tasks. Thus, by analysing and removing the waste, it eliminates unnecessary tasks of the bottleneck. The lean practices will give an understanding of the problem and how performance is limited, which means indications of where there are areas of improvement.

After identifying bottlenecks and waste, the contextual factors of the warehouse that are related to the picking efficiency are identified and analysed. Different contextual factors are described in Table 21. With the help of the current state, prior theory, and the wastes, it is possible to get an understanding of how contextual factors influence the choice of configuration. This is about analysing configurational decisions in relation to the context and the performance. Thus, understanding alignments between configuration and context that contributes to warehouse performance and misalignments that results in loss of performance. The wastes that were identified can be used as indicators for loss of performance. Thus, suggesting that there is a better choice of configuration.

The analysis will be used to develop propositions that suggests how to increase picking performance in a certain context. These propositions can then be used to develop recommendations for how picking performance can be improved at the warehouse. As the propositions are based on wastes and the contextual factors related to the picking efficiency, the recommendations will target the wastes related to the bottlenecks and improve the bottleneck resource. The propositions and recommendations are results from utilizing the current state of the warehouse and analysis to improve the picking process. Thus, they are results from utilizing the artifact, while the current state and analysis are the tools involved in the artifact.

4. THE CURRENT STATE OF THE WAREHOUSE

This chapter presents the empirical findings that have been collected during the case study at the Tetra Pak production warehouse. The empirical material is divided into five subchapters, which is seen in Figure 18, and it is based on the first part of the artifact. The first subchapter will present the design and equipment of the south and north warehouse and the yard. That includes the layout, handling and storage equipment, automation, information systems and labour management. By first getting an understanding of the layout and equipment, it is possible to grasp the warehouse operations that are of relevance for this thesis. Thus, the second subchapter will go through the picking operation, which is the focus of the study. It will also include the put-away and storage operation and the distribution operation because of their close linkage to picking. After presenting the configuration of the warehouse, meaning the warehouse operations and the design and equipment, the third subchapter will present the activity profiling of the warehouse. This includes the customer and warehouse profile, the assortment and SKU characteristics, the SKU popularity profile, the order characteristics, the picking characteristics, and the put-away characteristics. The fourth subchapter will present the picking performance of the warehouse, which is divided into service level and space utilization. Lastly, when all the data related to the current state of the warehouse has been collected and presented, it is possible to summarize the data in a value stream map. This will be done in the end of this chapter, in the fifth subchapter.

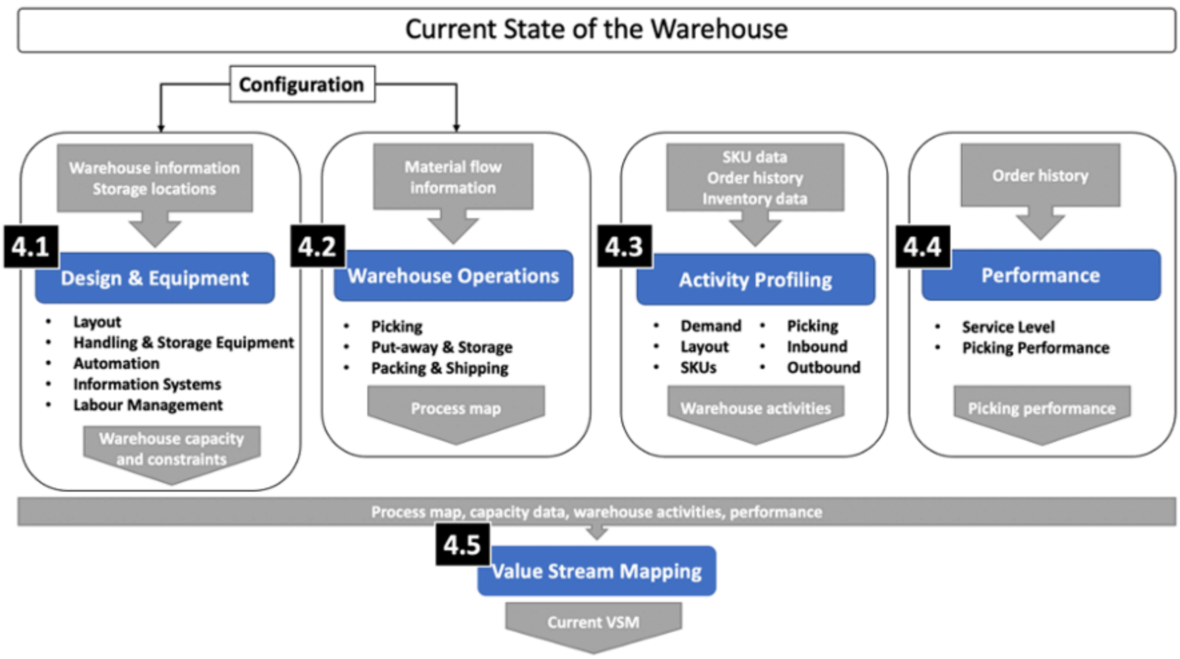


Figure 18. An overview of the different subchapters in the current state chapter.

4.1 Warehouse Design & Equipment

4.1.1 Layout

The layout of the north warehouse and south warehouse is seen in Figure 19. Items are received at the inbound area. They are confirmed and then placed at the received goods area. Larger items on pallets are put on the part of the received goods area that is closest to the pallet rack 41. This is because these items are often stored in pallet rack 41 or in the north warehouse. Smaller items are on the part of the received goods area that is closest to the quality control area. This means items that are going to be stored in the vertical storage lift or in other pallet racks in the south warehouse except pallet rack 41. The sorting area is a space that supports the vertical storage lift picking. They have for example load carriers, desks, and computers there. The distribution area is where the picked orders are placed. There are also two outbound areas, but it is the outbound area between the south and north warehouse that is used most often because it is close to the production. The outbound area here only means that they are entrance and exits for the forklifts, meaning that those are the areas where the material leaves from and that no materials are stored there.

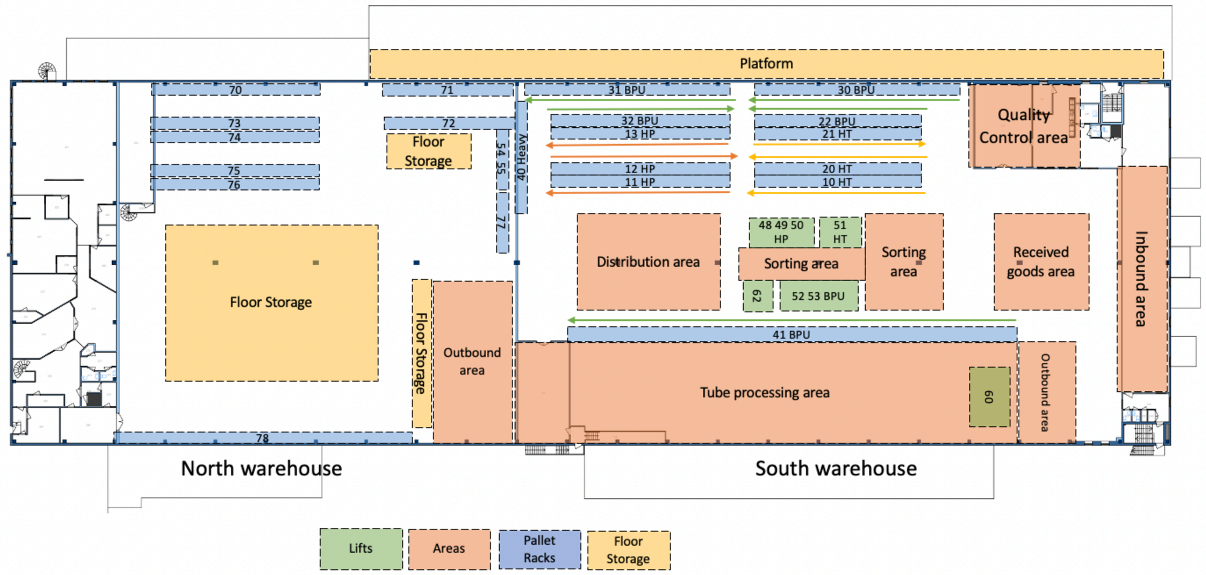


Figure 19. Layout of the north warehouse and south warehouse.

The south warehouse is the warehouse with most picking. The layout is divided into zones based on the three product categories: HP, BPU and HT. However, all the vertical storage lifts are collected into its own zone, except for lift 60. The collected lifts are divided by product categories, except lift 62 that can store pallets. The south warehouse mostly has broken-case picking from both the vertical storage lifts and pallets racks, but there are storage locations where whole pallets are picked. The arrows at the pallet racks in Figure 19 indicate how the storage location numbers increases. The north warehouse stores larger items. Thus, items are stored on the floor storage or pallet racks where they are picked as whole pallets. The north warehouse is also a cold storage.

The layout of the yard is shown in Figure 20. Very large material is stored here. The storage location 601 are special racks for storing tubes in wooden boxes. All other storage locations are floor storage. The storage locations at 603 111 have a roof to protect materials.

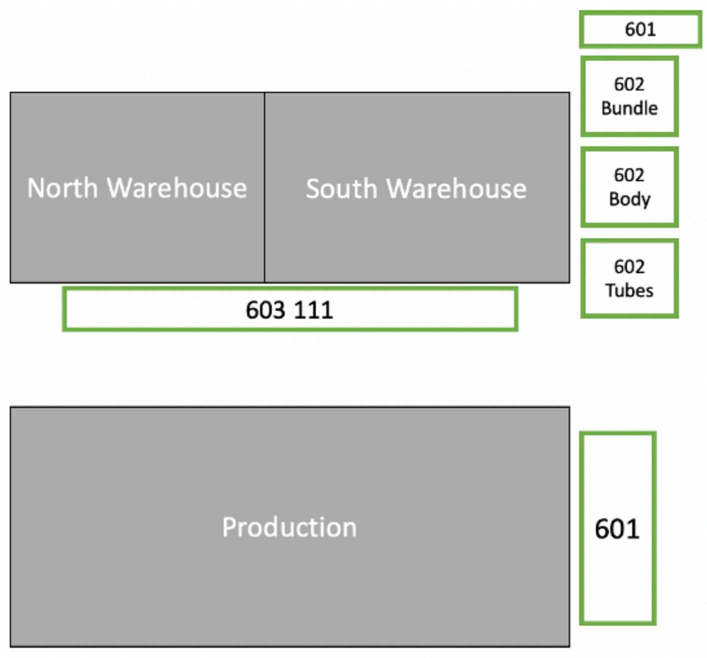


Figure 20. Layout of the yard.

4.1.2 Handling and Storage Equipment

The south and north warehouse and the yard has different storage equipment. There are two main storage equipment, which are automated vertical storage lifts and pallets racks. Also, the yard has special racks for tubes, see Figure 21. There is also floor storage, meaning that items are stored on the floor or ground. The storage locations have different bin types, meaning that they have different dimensions (depth, length, width). All pallet racks are single-deep, and all storage locations follow the principle first-in-first-out (FIFO). This means that the items that were stored first are the ones that are picked first. Furthermore, the buffer stock has been moved to another warehouse on the Lund site to increase storage locations in the warehouse. Before this it was stored on the highest level of the pallet racks in the south warehouse, except rack 41.

Figure 21. The tube racks at the yard.

Each storage location belongs to a storage type, which is a storage zone in the warehouse. Each zone stores similar kinds of items, for example similar sizes or same product category. Order labels are printed out in an increasing order based on the storage location number, which starts with the storage type. Thus, picking is done zone by zone. This also determines their picking routes because they pick according to how the labels are printed, which is the pick-list. For example, this means that they do the same route twice. One time for when they pick from the pull-out units, which are pallet locations at the bottom floor of the rack that can be pulled out as drawers. The second time when they pick from the storage locations above the pull-out units. This is because they are different storage types. Table 26 summarizes the different storage types. The warehouse also has different types of forklifts used for different purposes, which is summarized in Table 27.

Table 26. Summary of the storage types.

Area	**Storage Type**	**Storage Type Name**	**Storage Locations**	**Shared or dedicated**
South Warehouse	120	Vertical lift HP	48, 49, 50	Dedicated
	140	Pallet HP	11, 12, 13	Shared
	220	Vertical lift HT	51	Shared
	240	Pallet HT	10, 20, 21	Shared
	320	Vertical lift BPU	52, 53	Shared
	340	Pallet BPU	22, 30, 31, 32, 41	Shared
	440	Pull out units	10, 11, 12, 13, 22, 30, 31, 32, 40	Dedicated
	620	Vertical pallet lift	62	Dedicated
	640	Pallet (Heavy)	40	Shared
	643	Components Open area	Kajen, L2, L3, L5	Shared
North warehouse	160	Cables, CIP & Shells	55, 77, 78	Dedicated
	604	Cold Store Closed	111N	Shared
North Warehouse and Tube Processing Area	600	Tube Automat & Cold Storage	60, 70, 71, 72, 73, 74, 75, 76, 78	Shared
Yard	601	Tubes Outdoor Area	61	Shared
	602	Yard	Tubes, body, bundle	Shared
	603	Cold Store Covered	603-111	Shared
Another warehouse	644	Buffer stock	-	Shared

Table 27. Summary of the handling equipment.

Area	**Type of forklift**	**Purpose**
South warehouse	2 Order-picking trucks	Picking pieces from pallets in the south warehouse.
	1 Tow truck with five wagons	Used for distributing load carriers that are trolleys.
	1 Stacker truck (1-2 pallets)	Used for distributing pallets.
South and North Warehouse	2 Reach trucks (1,6 ton)	Picking whole pallets, heavy pallets, pallets stored far up in the rack.
North warehouse	1 Counterbalanced forklift (2 ton)	Picking pallets in the north warehouse.
Yard	1 Counterbalanced forklift (3,5 ton)	Picking pallets in the yard.

Often it is the order-picking truck and the reach truck that is used for pallet picking, where the first one is used for broken-case picking and the other one for whole-pallets picking. An order can require both trucks, and therefore they must switch between them. It happens that there are no forklifts left of the type that they need. That means waiting, taking the pick later or helping each other. The forklift is not only used by the picking team, but for other warehouse processes as well, such as service that handles additional picking or deliveries that handles orders that goes directly to customers and not the production.

4.1.3 Automation

The warehouse has seven automated vertical storage lifts, which works like vertical carousels but a shelve is retrieved instead of all shelves moving like a carousel. Seven of them are in the south warehouse. The vertical storage lifts 48, 49, and 50 store HP items. The lift 51 stores HT items. Vertical storage lifts 52 and 53 stores BPU items. The vertical storage lift 62 stores different types of material. These vertical storage lifts have shelves with several bins, which can be of different sizes. This means that several different SKUs are stored on one shelf. However, the shelves have a maximum weight capacity. Lifts 48 and 49 have maximum 500kg per shelf, lifts 50, 51, 52 and 53 have maximum 300 kg per shelf, and 62 have maximum 1000kg per shelf, where two pallets fit that weigh 500kg each. Lift 62 have several bins today, but it can store whole pallets as well. The items stored in the lift has been altered and it had heavier materials stored on pallets before, but today it stores smaller items in several bins like the other lifts. The heavy lift is also slower than the other ones because it can handle heavier materials. It also has a heavy lift aid close to it. Figure 22 shows one of the vertical storage lifts. The eight vertical storage lift, called 60, is in the part of the warehouse where they process tubes. It stores tubes after they have been processed. It has no bins as one shelf store one type of tube.

Figure 22. Vertical storage lift 50 with a retrieved shelf.

The vertical storage lifts have functions that supports picking. They have a pick-by-light function, which indicates what bin to pick from. The lifts also have screens that gives information such as a picture of the material, material description, material number, transfer order number and the quantity. To confirm a pick, they use foot pedals or the lift computer. Most vertical storage lifts also have the twin function where it prepares and gets the next shelf to make picking faster. All lifts have this function except 48 and 49. To avoid waiting, the picker should pick from 48 and 49 in parallel. Further, 48 and 49 have higher weight capacity per shelf. Furthermore, based on the interviews, there is space left for additional shelfs for these lifts. This is also shown in Figure 23 below, which includes how it looks today and an example of how it can look with more shelves. The different colours represent different shelf types, and the example is estimated to give 350 additional storage locations.

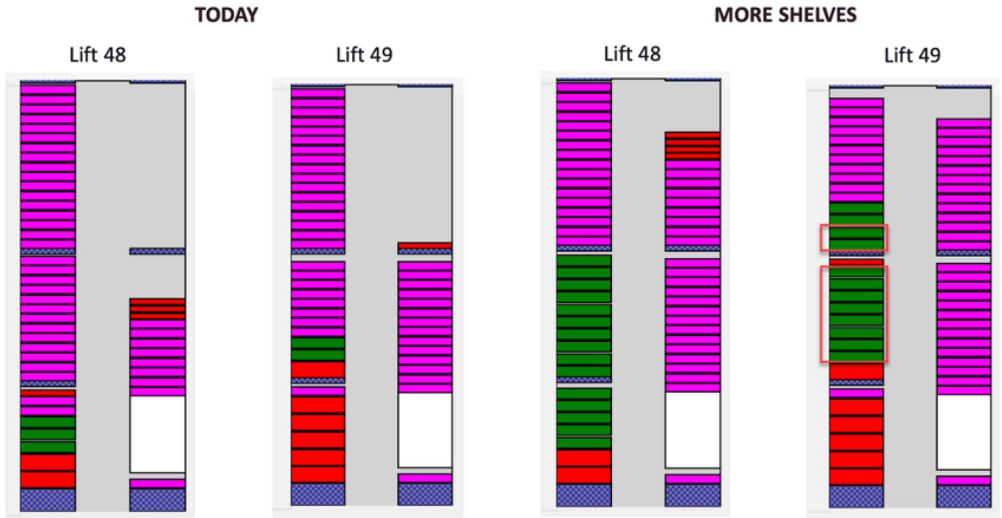


Figure 23. The free space in the lifts 48 and 49, and an example with more shelves.

Picking errors can occur in the lifts. Sometimes the screens give incorrect information. The workers should also confirm each pick after they have picked the item, but sometimes when several picks are on the same shelf, they grab all the items and then confirm all the pick-lines. This can contribute to picking errors because the worker will not be provided with information about the pick as the worker needs to confirm the pick to get information about the next pick.

Except the lifts as automation, the warehouse has scanners and truck computers used for picking and put-away to make sure that the correct product is stored or picked. When they pick from pallets racks, they use scanners to confirm the pick. This is done by typing in the order number in the truck computer and then scan the label on the bin to confirm the pick. Sometimes they cannot reach the label on the bin and then they confirm it in the truck computer. Scanners are also used for put-away in both the pallet racks and the lifts. They scan the label on the material and then the bin to confirm it. For the put-away and picking in the yard, the truck computer is only used. The scanners and truck computers are connected to the ERP system, which means that they give new information to the system, for example, the location of a material and its quantity or that transfer orders has been confirmed and at which times.

4.1.4 Information Systems

Tetra Pak uses the same ERP system throughout different departments. Thus, the information flow is shared between different parts of the organization. This allows connection between the purchasing, sales, and warehouse departments. The warehouse can access information such as sales order or purchasing orders. They can get information about the incoming goods and machines that are scheduled to be produced.

The ERP system has a WMS module, which is used by the warehouse and supports the processes of the warehouse. The warehouse has information on customer orders in terms of when machines are scheduled and released to the production. They also have information on all the storage locations and their physical characteristics, as well as the inventory and its physical characteristics. They also have their history kept in the information system, for example what material has been stored in the bins. The system allows them to automate some processes, for example when to replenish materials from the buffer stock or finding suitable locations to store the material. However, it happens that the information system suggest location that are already full, which is usually discovered when storing the material. The inbound workers then need to find another place to store the material.

To find suitable storage locations in the pallet racks in the south warehouse, the bins and materials are divided into different categories in the system, which is shown in Table 28. When searching for a storage location for a material, the system first tries to find a location with the correct storage type and storage section. If a location cannot be found, it tries to find a location with only the correct storage type. Otherwise, the workers must manually find a location for the material. The bin categories are also related to the forklifts because items that are lighter than 15kg can be picked by hand, which means from the order-picking truck. Items heavier than 15kg should be picked with the help of heavy lift aid that is available on the floor. Thus, items with storage section L01 need to have their pallet moved down with the reach truck and then placed back after the pieces have been picked. This can also be necessary when the storage locations are on the highest level. The warehouse is also designed so that a pallet rack section has the same storage section except for the pull-out units. This means that one type of forklift should be used for a whole section of the pallet rack, therefore minimizing the switching of forklift type.

Table 28. Explanation of the different storage sections.

Storage section	Characteristics of the material
Low (L01)	Items > 15kg
Medium (M01)	Items < 15kg Not frequently picked
High (H01)	Items < 15kg Frequently picked

Furthermore, the rule is that one bin should only store one item. However, there are a few bins that store multiple items, which are the bins for the floor storage locations. For example, the storage location 603-111 in the yard only has that name in the information system but can store many different materials.

The vertical storage lifts also have their own information system that allows inventory management and order management. This is connected to the ERP system. Thus, when picking or put-away happens in the vertical storage lifts, the ERP system also gets that information. Similarly, the truck computers also have their own system that is also connected to the ERP. There is also a business intelligence system that Tetra Pak uses to analyse and visualise data of the organization based on data from the ERP system. This includes data from the warehouse.

4.1.5 Labour Management

In the south and north warehouse, there are six people in the picking team, which are responsible for put-away, picking and distribution. Two people are responsible for picking in the vertical storage lift, two people are responsible for picking in the pallet racks, one person is responsible for put-away in the pallet racks and the last person is responsible for distribution. However, they help each other if they are done with their work. In the yard, there is mainly two persons, which are the yard responsible and the yard forklift driver. The yard responsible makes sure to visualise what should be picked or stored. The forklift driver of the yard makes sure to pick or store the material but is also responsible for loading and unloading trucks. Similarly, they help each other depending on the workload. According to the interviews, the warehouse struggles with a high percentage of sick leave, which is higher than many other places in the organization.

The warehouse uses some labour management strategies. They only have one shift per day and work from 7:00 to 15:38 Monday to Friday. They also have lunch and small breaks, that is approximately 1h in total per day. Furthermore, they try to rotate the workers in the picking team, which means rotating between picking from racks, picking from lifts and distributing. Some reasons for doing this is because if a worker is sick someone else can cover for that person as everyone is familiar with the different roles, and because variation contributes to better ergonomics. According to the interviews, bad ergonomics is an issue of the pickers, which contributes to the sick leave. Also, they normally do not take in temporary workers at the warehouse. Furthermore, flexible planning is offered to Tetra Pak employees. This means that they are allowed to have maximum -10 hours and can decide when they start and end in the day. However, they must be at work between 9:00-14:30 and the manager needs to approve it. In addition, workload balancing is not used as the workload is decided by the planned machine orders, which does not take workload balancing into account. However, they try to stabilize the work by realising orders a day early if possible and suitable.

4.2 Warehouse Operations

4.2.1 Picking

The picking process starts with transfer orders. A transfer order contains a list of items that should be moved from one place to another, for example from the inbound to a storage location or from a storage location to production. Transfer orders are printed automatically during the night according to what is scheduled in the ERP system. Each line on a transfer order, which is a pick-line, is a small white label that can be attached to items or load carriers. The information on a pick-line label is seen in Table 29 and a label is seen in Figure 24. A load carrier is different kinds of trolleys or pallets, where picked material is placed, see Figure 25. A load carrier should only contain material from one order. The information on a pick-line label is seen in Table 29.

Table 29. The information on a transfer order label.

Pick-line Information	Description
Requirement Number	The machine order number, also called sales order number.
Material Number	The number of the material.
Material Description	A description of the material.
Quantity	The quantity that should be picked.
Unloading Point	The location in the production it should be dropped off to. Indicates what type of load carrier that should be used.
Storage Location	The storage location it should be picked from.
Destination Location	The destination location it should go to. Often it is to a machine, which always have a number that starts with 501 and then the requirement number.
Transfer Order Number	An order with pick-lines that should be moved somewhere.

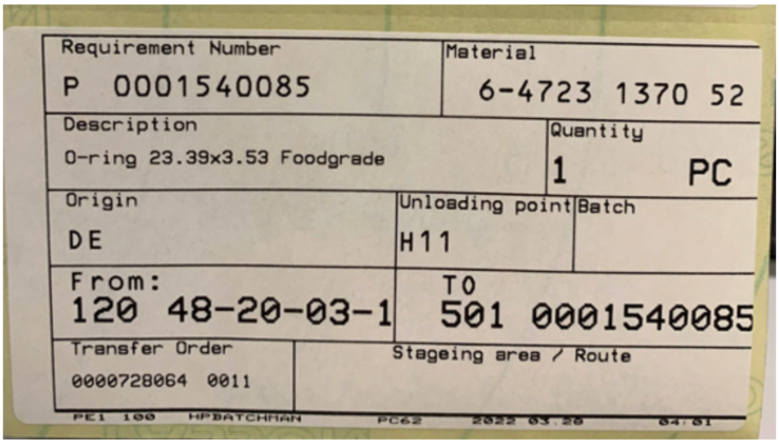


Figure 24. An order transfer label for picking.

Figure 25. Two types of load carriers.

Transfer orders are printed out one at a time, where the pick-lines for each transfer order are printed in an increasing manner according to the storage locations number, which starts with the storage type. This means that the picker picks one zone at a time. However, the picking is also done in parallel, meaning that the picking in the yard is done in parallel with the picking in the south and north warehouse. Thus, the pick-lines are printed at two locations, one for the yard and one for the south and north warehouse. Created pick-lines should be picked within 24 hours, otherwise it becomes a backlog. This means that the pick-lines printed during the night should be finished at the end of the day. However, as they only have one shift this means that they have 8 hours to finish the picking. Some pick-lines are printed out during the day, such as picks related to shortages or additional picks.

When the pickers arrive in the morning, they sort the pick-labels according to their transfer orders as they are printed as a long list with all labels attached to each other. In other words, they sort them into pick-lists, which are put in plastic holders by the lifts. Orders from the day before are prioritized by being placed first in line in the holders. They also put transfer orders with similar unloading points together. A picker usually picks one order at a time. However, sometimes they batch orders if they are similar, for example having the same unloading point. If orders are large, they take two orders at a time, but they can batch more orders if they are smaller. When batching, they sort during the picking by placing items on the correct load carrier. Batching also depends on the picker and their experience. In addition, it can happen that two pickers work on the same order at the lift picking if orders are very large.

The picking process at the south and north warehouse starts at the automated vertical storage lifts if the pick-list contains picks from the lifts. Firstly, the correct load carrier is chosen based on the unloading point of the order. If there are no load carriers in the warehouse, they get more at the platform, see Figure 19. Then they start the order in the information system of the lifts. The lifts automatically get the shelf with the items that are going to be picked. The picker picks and confirms the items, and the lift retrieves the shelf with the items on the next pick-line if it was not already on the shelf that was out. The picker puts the pick label on the item and places the picked item on the load carrier. It should be placed in a manner that makes it easy for the production operators to see it. If items are small, they should be places in plastic zipper bags. However, this depends on the load carrier as some have small compartments for smaller items. When the picks from the vertical storage lifts are finished, the pickers leave the load carrier for distribution to the production or to the pickers of the pallet racks.

If the pick-list contains picks from pallet racks, the pallet pickers continues with the order. The picking from pallets is either picking pieces from pallets or picking whole pallets, depending on the SKU and its size or weight. They mostly use the order-picking truck for broken-case picking and reach truck for the pallet picking. They use a pallet where they put picked items when picking from the order-picking truck, which needs to be consolidated with the items from the lifts on the load carrier when the picking is done. As the lifts, all items should have labels attached and be placed on the load carrier in a manner which makes it easy for the production operator. When the pallet picking is done, they leave the load carrier at the distribution area and mark it as ready for distribution with a green paper. The pallet pickers are also responsible for picking the tubes in the lift at the tube processing area. Furthermore, SKUs that are very large that cannot be distributed in a normal manner goes directly to the production

The process at the yard also starts with sorting the picking labels, which is done by the yard responsible. Papers with picking information such as material number, requirement number, and storage location are printed out manually. The paper is marked with a green tape to visualise picking and the picking label should be attached to the paper. The paper is placed in a plastic zip bag and the bag should be attached to the item to clearly visualise that the item should be picked. The picking should be done by the yard forklift driver, but the yard responsible helps when the other person is busy or if the item is not visible, for example if it is behind other items in the storage. The picked item goes directly to the production gate, that is the entrance to the production with high-performance doors where trucks can go through. The production operators pick their items at the gate. Thus, some items can be stored there for a long time.

Shortages of material can move directly from the inbound to the production, where workers at the inbound confirm these picks. However, some of these items need to go through quality control first and if they are approved, they are given back to the inbound that confirms the pick. The item is then placed at the distribution area, where the distributor makes sure that it gets delivered to production. If the item is large, it goes directly to the production gate.

Picking errors also occurs, meaning that the product or quantity was wrong, or similar issues. It also happens that the requested material was wrong in the first place. If the operators at the production notices that something is wrong, they log the issue and contact the warehouse service responsible. The service responsible figures out what has happened and picks new material if necessary and puts them at the distribution area or let the yard responsible know, which makes sure to get the material from the yard to the production gate. The worker responsible for deliveries, meaning orders that goes directly to customers, also picks their items themselves. However, they normally do not have items that is going to be picked from the yard.

All the picking processes that have been described above, is illustrated in Figure 26.

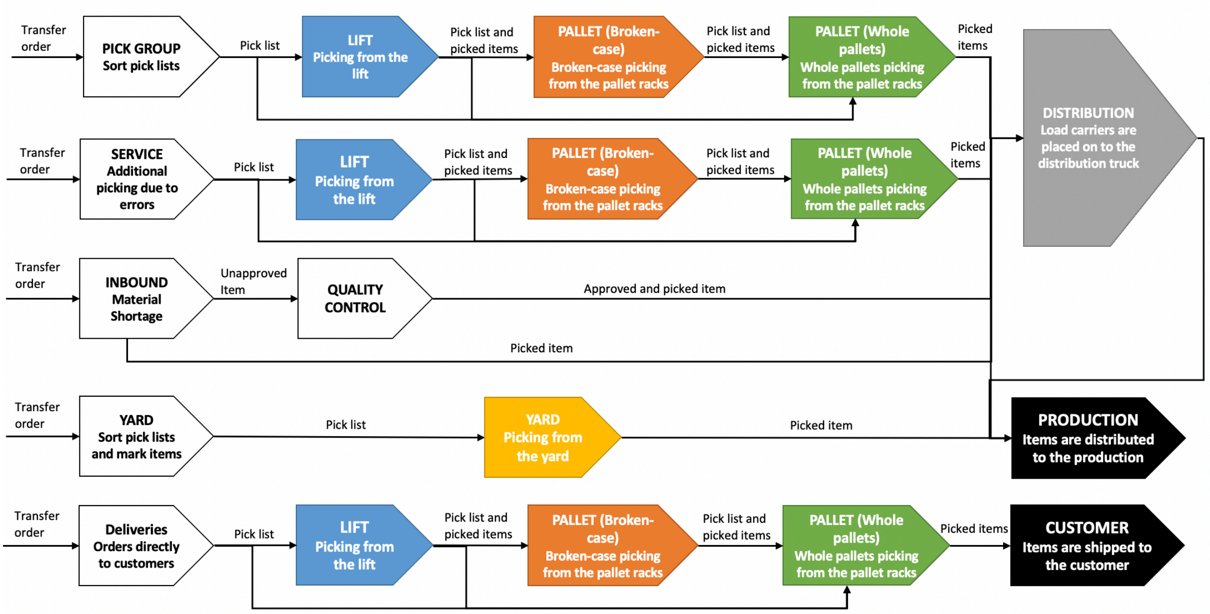


Figure 26. Visualises the picking processes of the Tetra Pak production warehouse.

4.2.2 Put-away & storage

Materials are received and confirmed at the inbound, where a suitable storage location is found for them. This is normally done by the ERP system, but if there are no suitable locations left it must be done manually by the workers at the inbound. Some materials are also replenished, meaning that the new quantity is added to the already stored ones. New items that are received are also handled manually because they have no previous information. When a suitable location is found, a transfer order is created and printed out with information about the storage location of the material, and the label is placed on the material. The labels for put-away are like the picking labels, but the main difference is that the put-away labels have a barcode on it, see Figure 27. SKUs that are going to be stored in the south and north warehouse are placed at the received goods area. The picking team then take the material and store them. Materials that are going to be stored in the yard are left outside at the receiving dock.

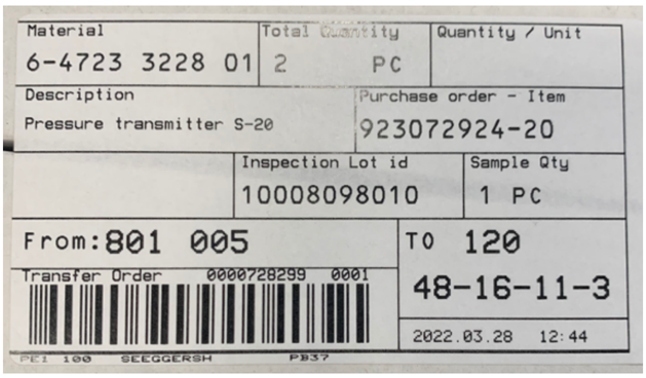


Figure 27. An order transfer label for put-away.

The process for put-away at the vertical storage lifts and pallets racks differs slightly. For the lifts, the information system for the lifts is started and a scanner is connected. They scan the label and lifts automatically gets the shelves with the intended storage location. They place the material in the correct bin and confirm the put-away. Often it is one transfer order per supplier, but the workers would like to have one transfer order per SKU because otherwise several lifts can start, which can interrupt the work of the other picker. Put-away in pallet racks starts with scanning the transfer order label and then the label on the storage location to confirm the put-away.

The yard put-away process looks like the process for yard picking. The yard responsible marks the received goods that are at the receiving dock with a paper with information such as material number, sales order number, and storage location. The transfer order label should also be attached to the paper, along with an orange tape to visualize put-away of the item. The forklift driver at the yard is responsible for the put-away, but the yard responsible can also help.

4.2.3 Distribution

When a transfer order is consolidated and done in the south and north warehouse, it is marked with a green sign, telling the distributor that the order is ready. They try to have as few load carriers as possible for one order. The pickers and distributor help each other to put the load carriers on to wagons, which are transported by a tow truck, and it is called "the train", see Figure 28. The train has five wagons, which means that several load carriers can be distributed at the same time. The distributor drives the load carriers out to the different unloading points in the production. However, material on pallets cannot be taken by the wagon and need to be taken with the stacker truck, which can take two pallets. The distribution is the same as the train.

Figure 28. "The train" that distributes load carriers.

Transfer order labels that are orange, indicates that the orders should be prioritized first and need to be distributed as fast as possible. This often means material shortages in the production or additional picks due to errors. Smaller items are put on a special load carrier in the distribution area. The load carrier can also contain transfer orders with only a few pick-lines. Material shortages can also be placed in a load carrier close to the inbound. That load carrier also contains special type of purchasing orders that should be moved to the production. Larger items are placed on the floor at the distribution area. If there are no orange transfer orders, it is the oldest transfer orders that should be distributed first.

The distributor is also responsible for bringing back empty load carriers, material that has been processed and should be stored again, returns, etc. If the distributor has no tasks, the person should help with put-away at the pallet racks.

Regarding the yard and distribution, it happens immediately after the picking because they are picked and go directly to the intended destination. This is because the yard often has large SKUs. Thus, it is hard to consolidate the picked items.

4.2.4 Summary of the Operations

The warehouse process and its operations are summarized in Figure 29. The main material flows are only visualised in the maps since they are the most important ones and to keep the visualisation simple. This means that smaller flows such as picks from the south warehouse that goes directly to the production gates or material shortage pickings that are picked in the receiving area are not included. Furthermore, operations such as receiving, and quality control are included to give an overview of the whole warehouse process, even though the focus is on put-away, picking, and distribution.

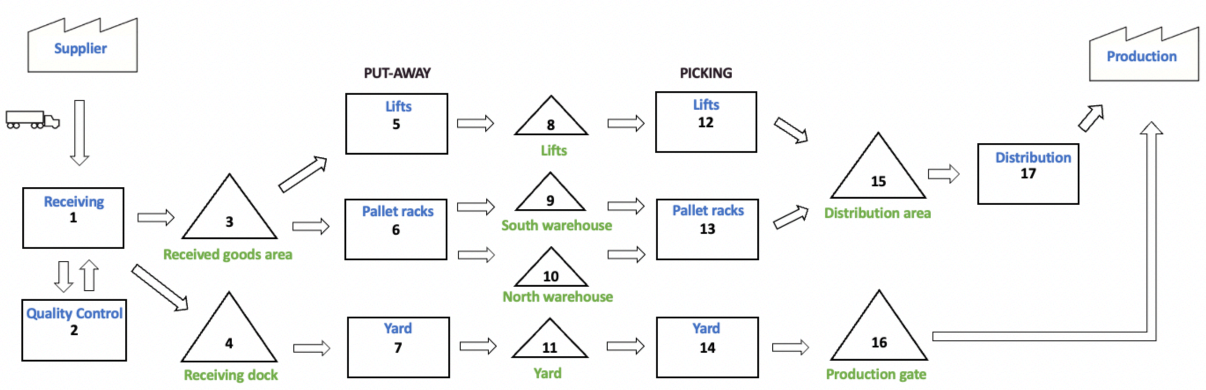


Figure 29. Warehouse material flow.

4.3 Activity Profiling

4.3.1 Customer & Warehouse Profile

The customers of Tetra Pak Processing Equipment are businesses that sell liquid food and beverages because they need to buy processing machines to make their products. According to the interviews, there are no certain demand seasonality except for summer and Christmas, which usually means holidays and vacations for the workers at Tetra Pak and in the industry in general. Figure 30 also indicate this, which shows the total number of picks throughout year 2021.

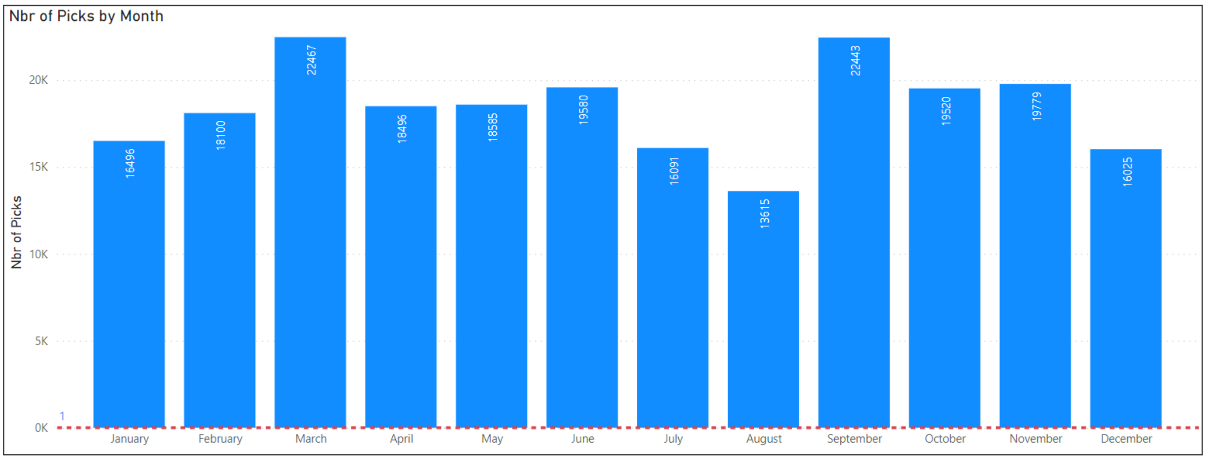


Figure 30. The total number of picks per month for 2021.

The different machines that Tetra Pak manufactures are divided into three categories: HP, HT and BPU. HP are homogenizers or high pressure pumps, HT are heat exchangers, and BPU stands for branded process units. The HP product group consists of 11 products, HT have 10 products, while BPU have 33 products. All machines are customized towards the needs of the customer. Thus, a product with the same name can look very differently depending on the customer. Furthermore, BPU products includes many different types of machines, but products that are HP or HT includes quite similar machines. Thus, HP or HT orders are more standardized than a BPU order.

The warehouse is a production warehouse, which mainly stores and consolidates raw materials for the processing machines that are going to be produced. However, some SKUs are products that have been processed in the production and should be stored again. Also, some orders go directly to the customers, for example spare parts. In addition, since the picked material goes to an operator in the production, it is necessary that the items are organized and visible in the load carrier. It should be clear what item it is by the attached picking label. Furthermore, some key metrics of the production warehouse can be found in Table 30. The floor storage locations can have more than one SKU stored there.

Table 30. Overview of some key metrics of the warehouse.

	South warehouse	**North warehouse**	**Yard**
Area (m^2)	3246	1971	2043
Height (m)	8	8	-
Number of storage locations	Pallets: 2543 Lifts: 5186	Pallets: 837 Floor: 71	Tubes: 134 Floor: 8

4.3.2 Assortment & SKU Characteristics

The purpose of the business and warehouse influences the SKUs that are stored in the warehouse. Raw material of large technical machines means a range of SKUs with different characteristics. They can be of different sizes and weights, which requires some special handling. Large or heavy items need special storage equipment. If they are very large, they are stored outside at the yard or in the north warehouse because of their floor storage locations. Heavy items should be stored in the storage equipment that can manage heavy loads. This means pallets racks, one of the vertical storage lifts or floor space, which have different capacities in terms of how much weight they can manage. Furthermore, the warehouse stores different types of tubes, where some are stored outside in tube racks, some are stored in a vertical storage lift in the tube processing area, and some are stored on the floor in the north warehouse. Also, some HP material that are stored in pallets and in vertical storage lifts are sensitive materials. Thus, they must be handled carefully. For example, heavy items cannot be placed on top of these. Other sensitive materials involve electrical components that need to be stored inside.

Table 31 shows the weight distribution of the stored materials. Most SKUs are light and have a weight below 5kg, where most of them are stored in the lifts. However, there are many SKUs that have a weight above 15kg, where most are stored in the south and north warehouse in pallets or on the floor. SKUs that weigh less than 15kg should be picked by hand. However, based on the interview it is not optimal to pick heavier SKUs from the order-truck due to bad ergonomics. SKUs that weigh more than 15kg should be taken down with the reach truck, where heavy lift aid should be used for piece-picking. SKUs that have 0kg probably does not have any data on their weight yet.

Table 31. The weight distribution of the stored SKUs. Based on snapshot from March 9th, 2022.

Weight (kg)	Lifts	North W	South W	Yard	Total
0	114	69	88	8	279
0.01 – 0.99	4257	87	541	36	4921
1 – 4.99	660	71	877	129	1737
5 – 9.99	94	22	386	45	547
10 – 14.99	36	20	169	10	235
Above 15	21	730	698	34	1483

Raw material to a lot of different machines that can be customized, also means a variation of materials. Table 32 shows that the warehouse had 6385 distinct materials in the warehouse, which were stored in 9202 locations, on March 9th, 2022. A big difference between total number and the distinct number means that the same material is stored in several locations.

Table 32. The total and distinct number of materials in the warehouse from March 9th, 2022.

Total number of stored materials	Distinct number of stored materials
9202	6385

As machines are customized, some materials are unique. Materials that are connected to a specific machine order is called special stock. Standardized material that is used for several machines is called anonymous stock. Table 33 shows the number of anonymous and special stock, and the last activity date of the SKUs in storage. The table shows that that some SKUs have not been picked for a couple of years. If the material has not been used in more than one year, it is called dead stock. There are 766 storage locations that have not been picked from since 2020 or earlier. Furthermore, if the dead stock is connected to a specific order, meaning special stock, it is not likely to ever be picked because the machine has already been manufactured. It is possible to see the future demand of the material in the ERP system and the special stock that had a last movement date in 2020 do not have any demand. Based on the interviews, the order responsible can change materials in an order without letting purchasing or warehouse know about it. If the material is unique, it means that both the old and new one will be purchased and stored in the warehouse, where the old item will never be used. Table 34 show the average number of days stored material have from different zones.

Table 33. Last movement date for the stored SKUs for the different zones. Based on snapshot from April 16th, 2022.

Year	Lifts	North W	South W	Yard	Total	Anonymous	Special
2017	3		1		4	4	
2018	2		11	4	17	17	
2019	37	2	28	8	75	74	1
2020	491	24	146	9	670	651	19
2021	1460	304	647	41	2452	2435	17
2022	3222	702	2070	177	6171	6059	112
Total	5215	1032	2903	239	9389	9240	149

Table 34. The average number of days since last movement of stored SKUs. Based on snapshot from April 16th, 2022.

	Lifts	NW	SW	Yard	Total
Average days since last movement	152	108	118	135	136

The warehouse also receives new material, which means that the material is not registered in the system. Figure 31 shows the total number of new materials that were introduced from September 2021 to February 2022. The average is 59 new SKUs per month. The increase of materials can, for example, depend on a new machine type. However, this does not always mean an entirely new material. It can mean that the old supplier was replaced by another supplier or that a supplier has changed the material and given it a new name. According to the interviews, there sometimes lacks communication between the warehouse, purchasing and sales because sales or purchasing can switch out a material to a new one and the warehouse does not always get that information. As a result, the warehouse keeps material that is not going to be used. This can also mean that a fixed bin is associated with a material that is not relevant anymore.

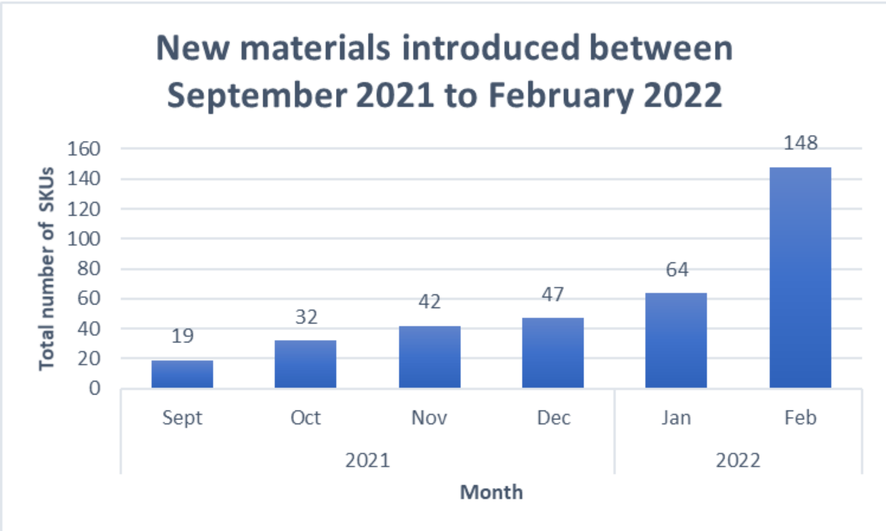


Figure 31. The number of new materials that arrive to the warehouse.

4.3.3 SKU Popularity Profile

Heat maps have been constructed to see where most activities in the warehouse are. It illustrates the total number of picks-lines for the different storage locations from September 2021 to February 2022. A green colour means that it has least picks compared to the other locations and the redder it is, the more picks the location has. Yellow means that it is between red and green. There are three different heat maps based on the different zones: vertical storage lifts, yard, and the south and north warehouse. To the left in Figure 32 is a heat map of the vertical storage lifts in the south warehouse. The HP vertical storage lifts are the ones that are picked from the most and the vertical storage lifts for the HT items and heavy items have least activity. The heat map of the yard is also seen in Figure 32 to the right. Most activities are for the tubes outdoor area (601), cold store covered (603) and the bundles (602). Heat map for the south and north warehouse is found in Figure 33 and a larger version with numbers is found in Appendix C. It shows that the south warehouse has more activities than in the north warehouse. It also shows that the BPU and HP pallet racks are mostly picked from.

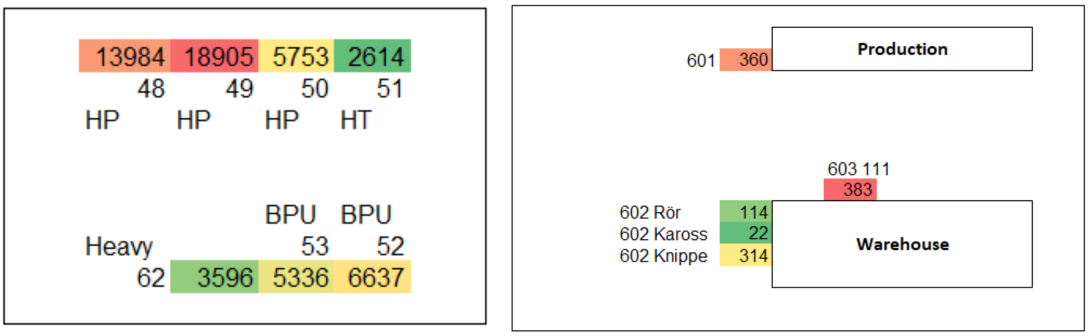


Figure 32. Heat map of the lifts in the south warehouse (left) and the yard (right).

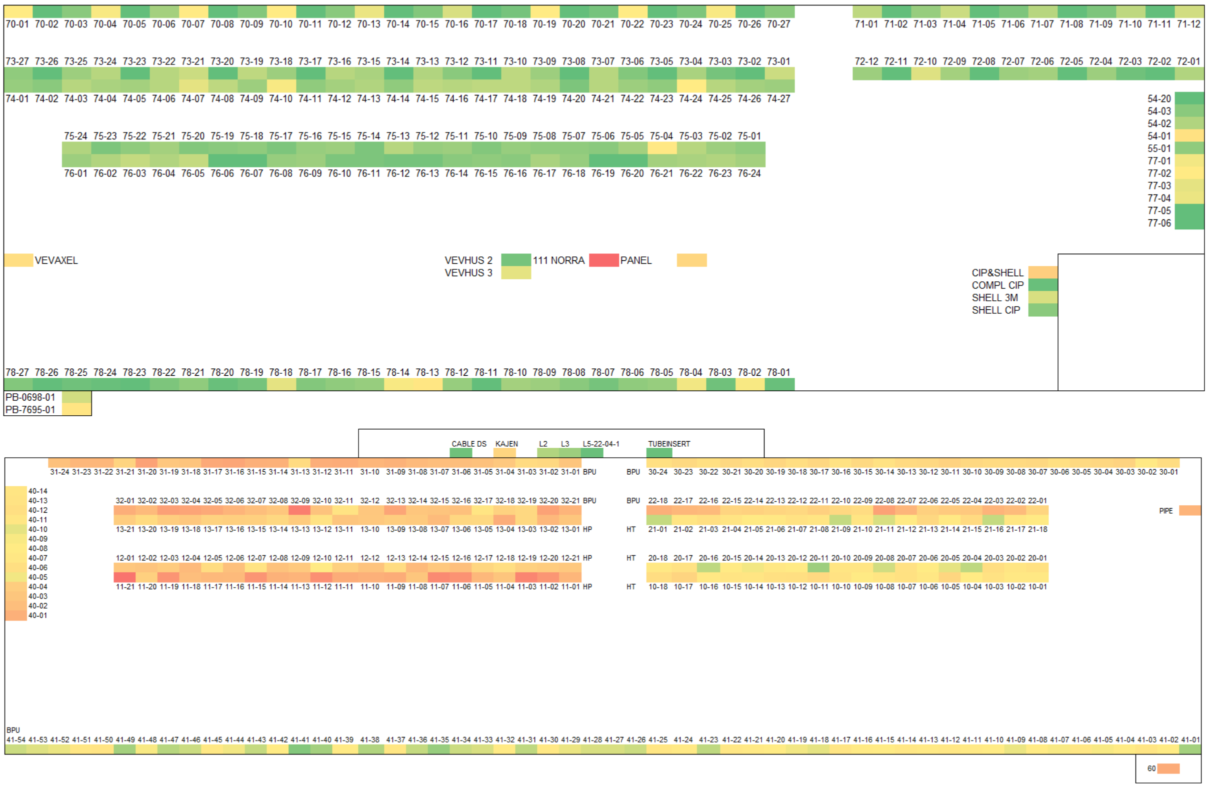


Figure 33. Heat map of the south warehouse (below) and north warehouse (above).

The heat maps show that the HP product family have most activity in the lifts, but also have a lot of activity in the pallets, together with the BPU. HT material seems to have the lowest number of picks. Table 35 summarizes the number of picks based on the storage locations that are associated with a product category. This also shows that the HP lifts have by far the most picks.

Table 35. Total number of picks from the storage locations that are related to HP, HT and BPU.

	Lifts	**Pallet**
BPU	11 973	11 783
HT	2614	2124
HP	38 642	8614

The SKUs with most picks between September 2021 and February 2022 from different warehouse areas are seen in Appendix D. Table 36 shows the total number of picks based on the 15 most picked materials from different zones. It also shows how much it represents based on all the picks between September 2021 and February 2022. This shows that the activity is less concentrated around a few SKUs for the lifts and the pallets in the south warehouse. In contrast, the north warehouse and yard have fewer SKUs that the activity is based on. Furthermore, Table 37 shows the most popular SKUs and how the picks are distributed between months. It is an example of how the activity is evenly distributed between the months. These are also shown in Appendix D with more information such as description and storage types.

Table 36. The distribution of the top 15 picked materials for different zones between September 2021 to February 2022.

Area	**Lifts**	**South Warehouse**	**North Warehouse**	**Yard**
Number of picks	3392	1899	764	478
How much the top 15 picked materials represent of all picks (%)	5.96	8.06	27.98	40.07

Table 37. Example of how picks are distributed between the months.

Material	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Total**
6-4722 8753 01	68	60	50	61	52	48	339
6-4723 1370 52	68	60	50	61	52	48	339
342991–0101	50	48	44	44	41	40	267
315102–0198	45	43	41	41	37	41	248
90087–0015	47	43	38	45	35	38	246
6-4350 8400 78	44	41	42	38	35	40	240
6-4723 1370 16	31	40	38	39	32	37	217
6-4723 1370 08	41	43	24	51	31	15	205
311103–0460	42	36	26	34	33	25	196
6-4723 1370 15	38	40	17	47	33	15	190

Appendix D shows that the most popular SKUs from the pallets in the south warehouse are from the storage type 440, the pull-out units. This storage type has a dedicated storage policy because it is supposed to have frequently picked and heavy material. However, Figure 34 shows that the storage type contains frequently picked materials that are not heavy and heavy materials that are not frequently picked, based on picking data between September 2021 to February 2022. It also shows that there are materials with low number of picks and low weight. Table 38 shows the number of materials that have less than 20 picks for the storage type 440 that are HP, HT, and BPU and less than 5 picks for 440 that belongs to the heavy pallet rack. It also shows the number of materials that have more than 30 picks for the pallet locations that are not pull-out units that belong to HP, HT, and BPU. This means, storage type 120 for HP, 220 for HT, and 320 for BPU. The table also shows the number of materials that have more than 10 picks for the pallet locations that are heavy but not 440, which is called storage type 620. This indicates that some materials that are stored in the pull-out units are not optimal due to their low pick frequency and there are other materials with higher pick frequency that are more suitable of being stored there. 20 and 5 picks were used for the 440 and 30 and 10 picks for the other pallet locations to have a margin between the materials. Otherwise, if materials from both 440 and other pallet locations were around, for example, 25 picks, it would not indicate that some materials are more suitable at the pull-out units. Also, it was found that the heavy material did not have as many picks as the other ones, which is why 5 and 10 picks were used, in contrast to 20 and 30 picks. Appendix E contains lists of the materials in the Table 38. It also includes their weight and storage bin type.

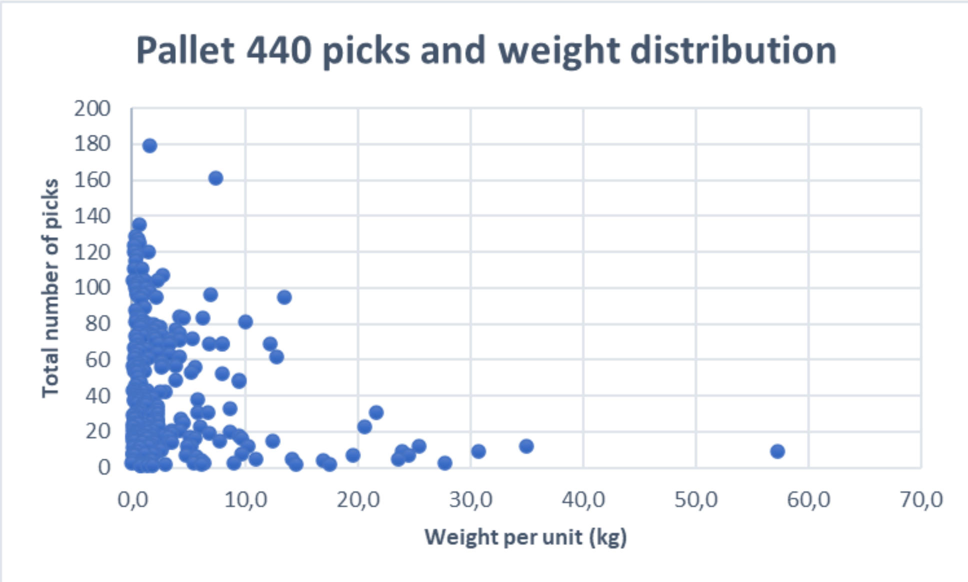


Figure 34. The number of picks and weight distribution for picks from the pull-out units between September 2021 to February 2022.

Table 38. Number of materials that have the most and least picks for the south warehouse pallet picking between September 2021 to February 2022.

	440 with less than 20 picks	**Other pallet locations with more than 30 picks**
HP	21	34
HT	5	8
BPU	43	24
	440 with less than 5 picks	**Other pallet locations with more than 10 picks**
Heavy	7	8

The vertical storage lift 62, with storage type 620, also has a dedicated storage policy and can store heavy materials in pallets. However, Figure 35 shows that it has frequently picked materials have low weight, and that the heavy materials have low picking frequency. Meanwhile, Figure 36 shows that there are items with a weight above 5kg that have been picked more than 15 times between September 2021 to February 2022. They are also stored in pallets in the south warehouse and have the storage bin type P1, which is a pallet with one pallet collar, and they can be stored in the lifts. Appendix F contains lists of the materials. The lift is also more ergonomically to use than pallets when it comes to broken-case picking because items are in the same level as the waist of the picker.

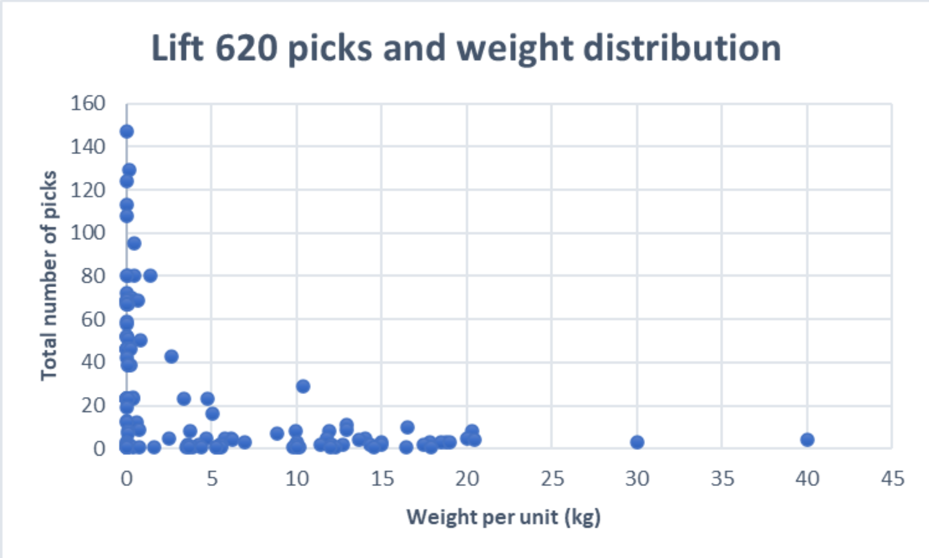


Figure 35. The number of picks and weight distribution for picks from storage type 620 (lift 62) between September 2021 to February 2022.

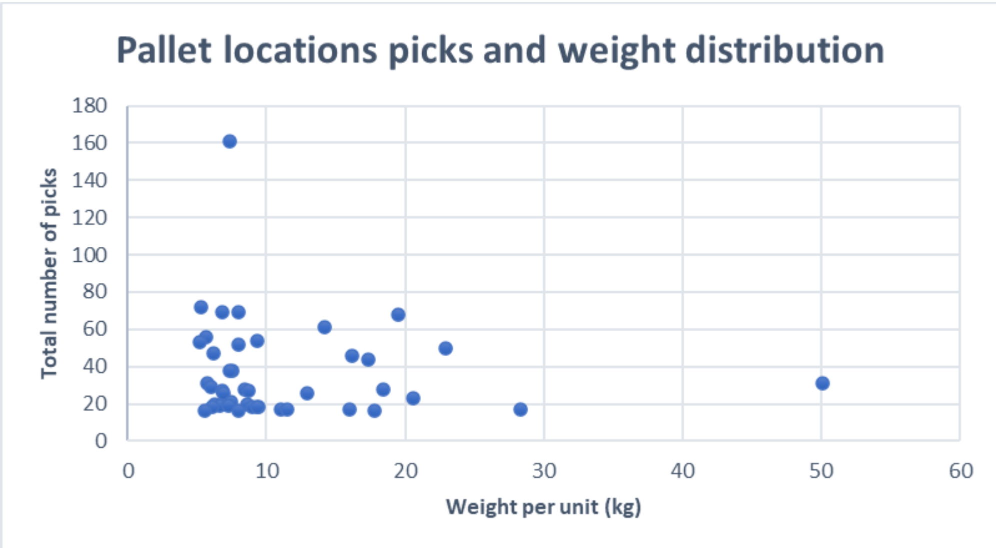


Figure 36. The number of picks and weight distribution for picks from storage types 140, 240, 340 and 440 with a P1 bin, weight above 5kg, and have been picked more than 15 times between September 2021 to February 2022.

As mentioned earlier, when the ERP system searches for storage locations for the pallets in the south warehouse, it uses storage sections. Table 39 shows the most frequently picked materials from the south warehouse and what storage section they have been picked from, but also what primary storage section that the material has. It shows that many of the items are defined as M01, which means a low pick frequency and as they are the most picked items they should be defined and picked from H01. The table also shows that items are not placed in their intended storage section because some items are picked from different storage sections. This is due to the maximum space utilization as there are no suitable locations left. As a result, materials are not placed in their optimal storage locations. For example, the third item has a storage section M01, but has been placed and picked from a L01 location. This means switching of trucks because a rack section is either L01, M01, or H01, and L01 means that the reach truck must be used to pick down the pallet and use heavy lift aid to pick the material and then put the pallet back again. While M01 and H01 use order-picking trucks.

Table 39. The 15 most picks from south warehouse pallet locations and their storage section.

Nbr	Material	Storage Type	Primary section	H01	L01	M01	Total	Weight per unit
1	6-9612 93 9303	340	M01			117	117	0,16
2	6-4016 0302 70	140	H01	89			89	0,36
3	6-1 647600 05	240	M01		11	68	79	0,84
4	6-4723 2294 01	140	L01	12	38	21	71	19,54
5	6-4722 1232 03	140	L01		50	20	70	0,10
6	6-4723 0461 01	140	M01	19		50	69	4,48
7	6-4241 0010 51	140	L01		69		69	18,52
8	6-4722 1230 03	140	L01		69		69	14,20
9	6-990397 18	240	0			67	67	0,04
10	6-4723 2291 01	140	L01	7	40	20	67	50,40
11	6-4722 7643 02	140	L01		63	3	66	22,90
12	6-4723 2300 01	140	M01	58		7	65	1,84
13	6-4723 2301 01	140	M01	55		10	65	1,70
14	6-4723 2293 01	140	L01		26	37	63	3,94
15	6-34144 6195 1	340	M01	28		32	60	0,66

4.3.4 Order Characteristics

Transfer orders can be similar in terms of unloading points or belonging to the same product family. An unloading point is associated with a certain product category. For example, an unloading point that starts with H is associated with HP material. Thus, a picker knows what lifts and pallets in the south warehouse that they are going to pick from, which is also indicated by the storage type number. Machines are also produced in stages, meaning that a transfer order is not equal to all the picks for an entire machine. Figure 37 shows the different unloading points and the total number of transfer orders that were created between September 2021 and February 2022.

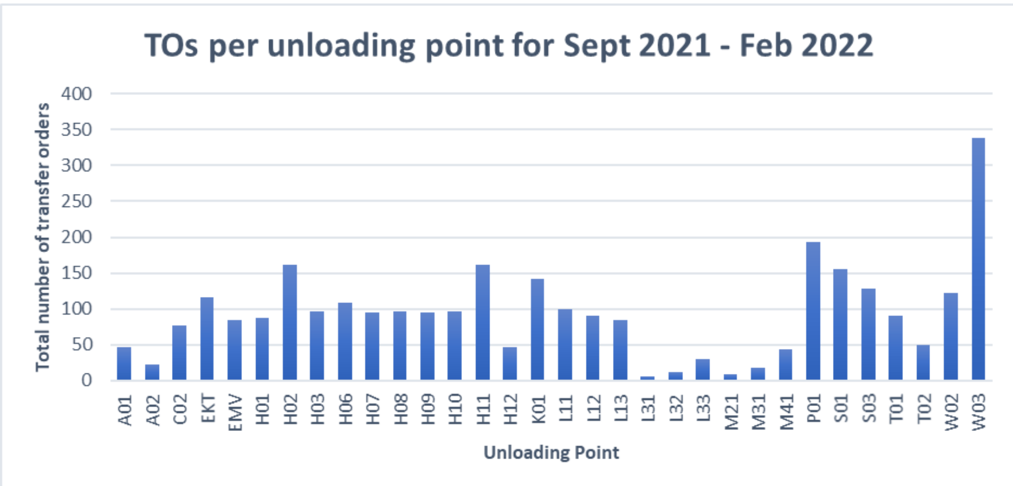


Figure 37. Total number of transfer orders per unloading point for September 2021 to February 2022.

Table 40 shows the average number of lift and pallet pick-lines per transfer order for a certain unloading point. This is based on orders that the pickers have logged themselves. They recorded the time it took to pick the order and how the distribution looked like in terms of how many load carriers that were used and which truck that it was distributed with. The time for a pick from the lift can vary but on average it is one minute. It also shows that the time for a pallet pick can vary even more, with an average on 2.8 minutes and a maximum on 9.7 minutes.

Table 40. The average number of lift and pallet pick-lines per transfer order for unloading points, the average time to complete the picks and the average number of load carriers used.

		Lift			Pallet			Distribution	
Unloading point	**HP/ HT/ BPU**	**Pick lines**	**Total Time (min)**	**Time per pick (min)**	**Pick lines**	**Total Time (min)**	**Time per pick (min)**	**Load carriers train**	**Load carriers stacker**
A01	BPU	23	12	1,0	11	16	1,7	1,7	0,2
A02	BPU	26	15	1,2	36	28	1,1	1,7	0,7
C02	-	2	3	1,3	1	9	9,7	0,0	0,8
EKT	BPU	12	11	1,1	23	15	1,0	0,1	1,0
EMV	BPU	42	22	0,7	50	30	0,8	0,3	1,2
H01	HP	180	81	0,5	30	63	3,8	2,2	2,3
H02	HP	41	29	0,7	13	30	3,3	1,5	1,6
H03	HP	20	15	0,8	8	16	2,0	0,9	1,2
H06	HP	122	55	0,5	27	63	3,0	2,3	2,1
H07	HP	41	23	0,6	4	6	2,3	0,6	0,0
H08	HP	37	20	0,6	12	25	2,2	0,8	1,2
H09	HP	13	12	1,0	5	10	2,4	0,9	0,1
H10	HP	23	15	0,7	10	13	1,4	0,9	0,7
H11	HP	32	22	0,7	3	4	1,6	0,3	0,7
H12	HP	18	17	1,0	2	6	2,5	0,2	0,8
K01	-	10	11	1,4	4	8	2,1	0,4	0,3
L11	BPU	11	8	1,6	5	10	4,9	0,5	0,9
L12	BPU	4	4	1,4	10	35	3,4	2,7	1,6
L13	BPU	38	17	0,5	45	42	1,5	1,6	1,5
L31	BPU	56	45	0,8	12	35	2,9	3,0	0,0
L32	BPU	7	5	0,7	0	0	-	0,5	0,0
L33	BPU	33	16	0,6	4	9	2,4	1,1	0,0
M21-41	HT	2	4	2,8	1	2	4,5	0,5	0,0
P01	-	13	9	1,3	8	16	2,6	0,3	1,3
S01	HT	5	7	1,5	17	42	3,4	2,0	0,5
S03	HT	4	6	1,4	3	7	2,2	0,1	0,9
T01	BPU	15	8	0,7	18	17	3,0	0,5	0,7
T02	BPU	18	12	1,7	7	13	3,2	0,1	1,1
W02	BPU	23	14	0,9	30	32	1,2	0,8	0,4
W03	HT	2	3	2,0	1	5	4,1	0,3	0,5
Average		**29**	**17**	**1,0**	**13**	**20**	**2,8**	**1,0**	**0,8**

Furthermore, Table 40 shows that the number of picks for a transfer order can vary depending on the unloading point. It is also important to notice that some of the unloading points have the same definition as the storage sections, such as H01 and M01. However, unloading points are often connected to the orders, while the storage sections is connected to materials or locations. Thus, it is possible to distinguish them in the report. Also, the discussions often states if it is the storage sections or unloading points that are discussed.

Since machines are customized, the transfer orders with the same unloading point can also vary. Table 41 shows an example with H01 orders and how they can vary in both number of pick-lines for lifts and pallets, but also the time to complete the order. This is also based on the logged data by the pickers. A pick from the lift can take less than a minute in average, but for the pallet it can vary from 1.3 to 3.7 minutes. The data did not include the yard, but according to the interview with the yard responsible, a pick can take between 5-60 min and often there are 1-2 picks per transfer order, but sometimes there can be up to five picks, which data from the ERP system confirms. Table 42 confirms how the same type of machines can vary in pick-lines for their different transfer orders. There were no picks from the yard for those machines.

Table 41. Different H01 orders and their number of pick-lines and the time it took to complete.

Transfer order	Lift			Pallet		
	Pick lines	Total Time (min)	Time per pick line (min)	Pick lines	Total Time (min)	Time per pick line (min)
Order 1	214	84	0,39	29	75	2,6
Order 2	183	72	0,39	45	60	1,3
Order 3	183	86	0,47	45	63	1,4
Order 4	173	82	0,47	23	33	1,4
Order 5	173	63	0,36	33	65	2,0
Order 6	164	68	0,41	45	90	2,0
Order 7	170	75	0,44	43	60	1,4
Order 8	168	77	0,46	30	110	3,7
Order 9	176	74	0,42	31	60	1,9
Order 10	198	70	0,35	30	60	2,0

Table 42. Number of picks for complete machine orders for three different types of machines.

Machine Order	HP machine type 1		HP machine type 2		HP machine type 3	
	Lift	Pallet	Lift	Pallet	Lift	Pallet
Order 1	294	44	236	56	386	101
Order 2	244	52	227	57	290	97
Order 3	271	41	243	61	364	100
Order 4	222	38	328	86	366	99
Order 5	234	42	269	64	315	96

4.3.5 Picking Characteristics

The number of pick-lines that needs to be picked each day varies. Figure 38 shows the created pick-lines in January and February 2022, which illustrates how it can vary a lot between the days. It does not take the non-working days such as weekends into account because there are no shifts then.

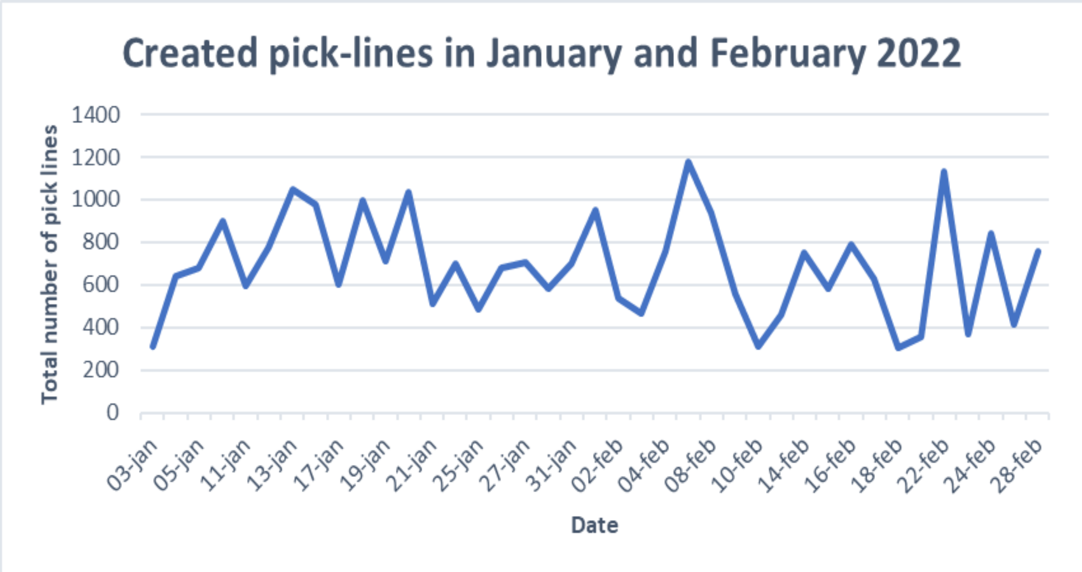


Figure 38. The total number of pick-lines in January to February 2022, excluding non-working days.

Figure 39 shows the amount of picking in different areas of the warehouse. It clearly shows that the most picking happens from the lifts and then the south warehouse pallet racks. The north warehouse and the yard have least number of pick-lines. The average pick-lines per day for the different zones for each month is also quite similar in terms of zones, seen in Table 43. The table also includes their standard deviation, which indicates fluctuations between days.

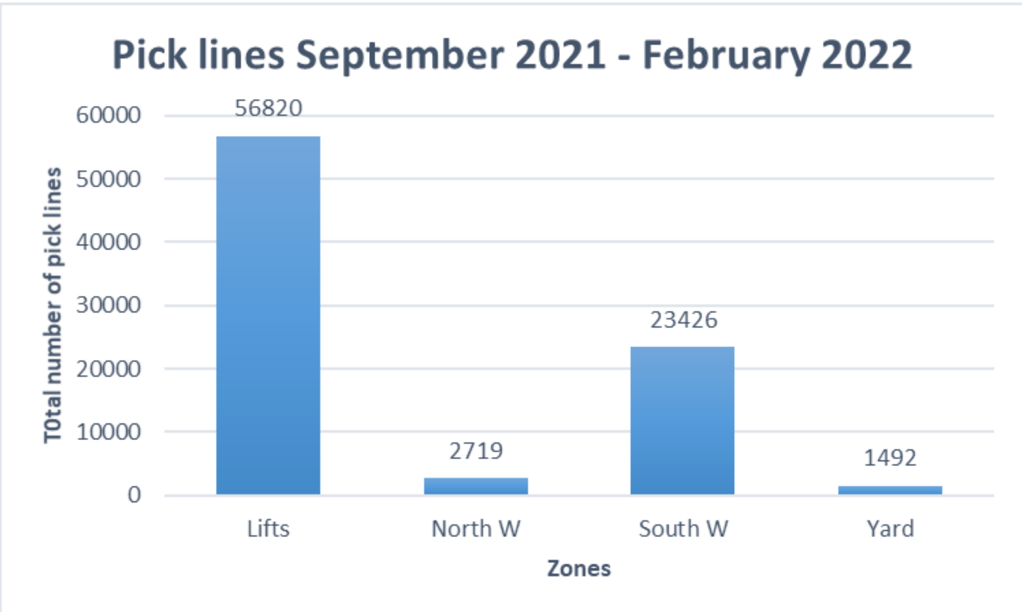


Figure 39. The number of pick-lines in different parts of the warehouse and yard.

Table 43. Average and standard deviation of number of pick-lines per day for the different zones.

		Average					Standard Deviation			
Year	**Month**	**Lifts**	**North W**	**South W**	**Yard**	**Total**	**Lifts**	**North W**	**South W**	**Yard**
2021	**September**	492	21	209	13	735	141	8	58	63
	October	470	22	204	12	708	132	9	50	56
	November	428	23	193	13	657	203	8	49	54
	December	427	21	157	10	615	178	13	81	91
2022	**January**	494	22	187	13	716	154	7	48	52
	February	440	22	182	11	655	168	9	49	53
	Total	458	22	188	12	680	167	9	59	6

Figure 40 shows that most pick errors are related to the HP product family. This is based on the logged errors done by the production operators in 2021, which can be seen in the BI system. Furthermore, Figure 41 shows the different types of pick errors that has been done for the HP picks. This shows that the most common errors are that the article is missing or a part of it, the article is wrong, and the quantity is wrong. However, missing article can sometimes depend on shortages, thus it was not a pick error in the first place. Table 44 shows that most pick errors for the top three pick error types are related to the lifts. Similar findings were shown in a retrieved document containing an analysis of pick errors between January to September 2021.

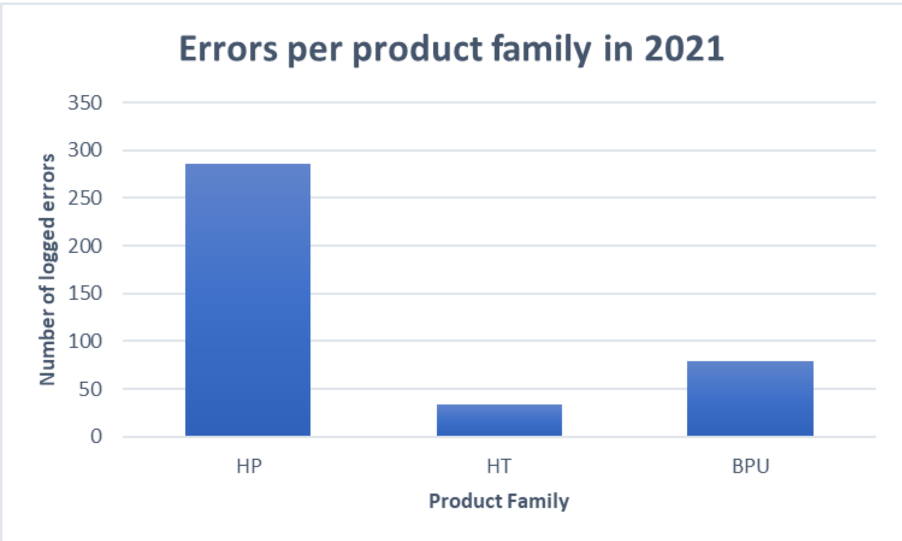


Figure 40. The number of warehouse errors for the different product families.

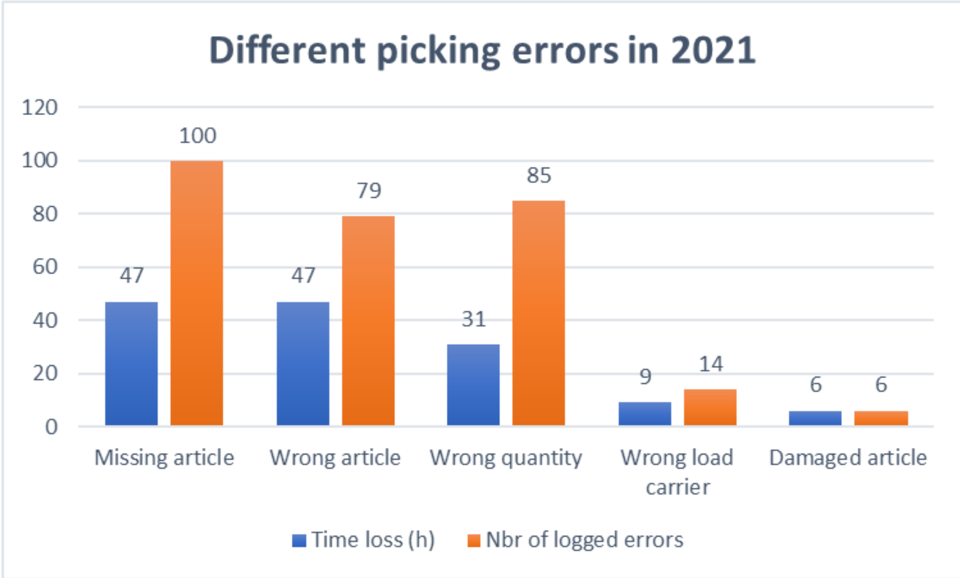


Figure 41. The different types of warehouse errors for HP and their frequency and time loss.

Table 44. The number of pick errors for the top three errors type for HP based on the different warehouse zones.

Zone	**Missing article**	**Wrong article**	**Wrong Quantity**	**Total**
Lift	70	58	59	187
Pallet	12	23	9	44
Floor	5		1	6
No data	13	4	10	27
Total	100	85	79	264

4.3.6 Put-Away Characteristics

The number of SKUs that needs to be stored each day varies. Figure 42 shows the number of put-away in January and February 2022. It excludes non-working days due to not having shifts.

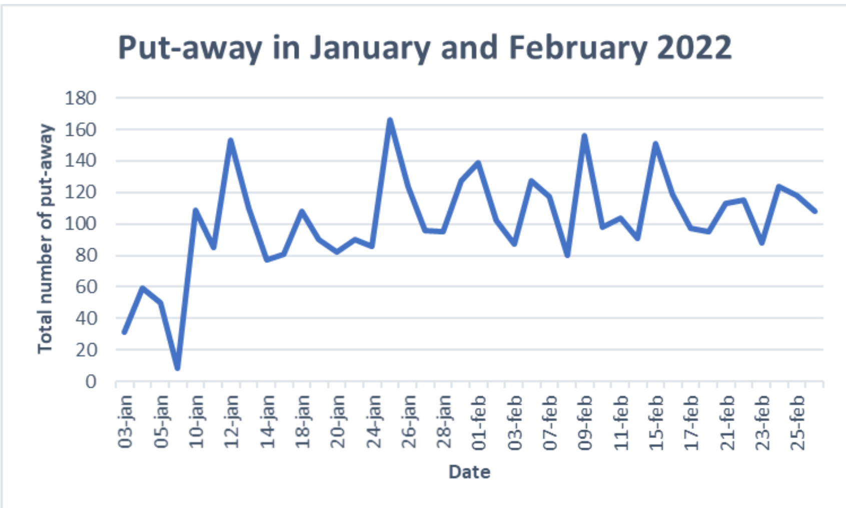


Figure 42. The number of put-away in January to February 2022, excluding non-working days.

Figure 43 shows the number of put-away in terms of different areas of the warehouse. Most put-away happens in the lifts but put-away in in the south warehouse in pallets is not far behind. This could be compared with the same graph for picking, where it was clear that most picks belong to the lifts and the south warehouse was almost half of that (see Figure 39). This is because SKUs in the lifts are stored in a higher quantity than the SKUs that are stored on pallets because smaller and lighter items are stored in the lifts. The same reasoning goes for the north warehouse and yard, which often stores larger items. This can be seen in the data because the put-away is almost the same as the picking. Furthermore, Table 45 shows the average put-away per day for the different areas for each month, which shows a quite similar average each month and for the different areas. The table also includes their standard deviation, which indicates fluctuations between days.

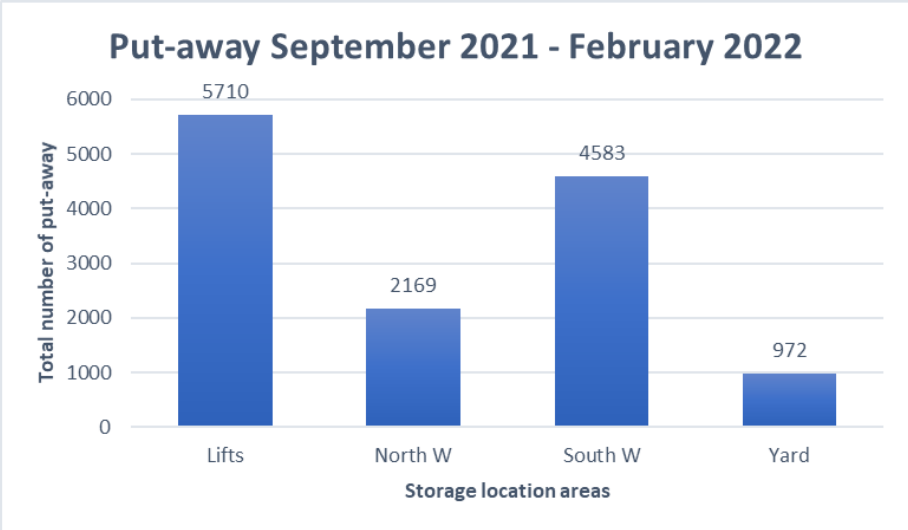


Figure 43. The number of put-away in different parts of the warehouse and yard.

Table 45. Average and standard deviation of number of put-away per day for the different zones.

		Average					Standard Deviation			
Year	**Month**	**Lifts**	**North W**	**South W**	**Yard**	**Total**	**Lifts**	**North W**	**South W**	**Yard**
2021	**September**	48	16	37	9	110	15	7	14	5
	October	54	19	41	10	124	14	8	11	6
	November	45	18	42	9	114	15	11	12	5
	December	38	14	32	7	91	10	7	12	6
2022	**January**	36	18	32	7	93	14	11	14	2
	February	52	18	35	7	112	13	7	11	5
	Total	45	17	36	8	106	15	9	13	5

The average time per put-away for the lift and pallet is shown in Table 46. These are based on previous analysis done by the organization. According to interviews with the pickers, picking usually takes longer time than put-away. However, they also said that it depends. For example, if items are going to be consolidated with old material it can take longer time. In contrast, putting away a whole pallet is quick. It also depends on the volume. They mentioned that it takes a minute or few minutes though.

Table 46. Average time per put-away, based on previous analysis made by the warehouse.

Area	Time per put-away (min)
Lift	1,3
Pallet	2,6

4.4 Performance

4.4.1 Service Level

The warehouse has 24 hours to pick the transfer orders that are created each day and because they only work one shift, that means 8 hours. Table 47 and Table 48 shows the capacity in terms of the number of pickers that picked during February for the different warehouse areas. The data confirms that there are about 6 pickers in total. The tables also show how many pick-lines that were picked the day they were created, which means day 0. Backlog indicates the number of pick-lines that were picked after day 0 and service level means the percentage of the created picks that they managed to pick in time. The service level in the table is green when the backlog has 0-3 pick-lines, which means that they were able to pick all the lines in 24 hours. 0-3 picks are used because additional picks that service is responsible for is included in the data and usually consists of a few picks. Furthermore, the yard can sometimes wait with some pick-lines to the day after when they know that the items are of no rush in the production. The tables also shows that all the different areas have backlogs, but the pallet picking have most backlog. It also shows that there is no regularity in the number of picks they can manage. This was also confirmed from the interviews with the pickers, who also explained that the number of picks depends on who is working as well due to different experiences and skills of the workers.

Table 47. The capacity and service level during the first part of February 2022.

		1/2	2/2	3/2	4/2	7/2	8/2	9/2	10/2	11/2	14/2
Lifts	**Pickers**	2	2	2	2	2	2	2	2	2	2
	Day 0	564	334	321	518	746	662	330	168	333	500
	Backlog	124	23	1	1	105	3	10	0	1	6
	Service level	82%	94%	100%	100%	88%	100%	97%	100%	100%	99%
Pallets	**Pickers**	3	3	2	3	2	2	3	2	2	3
	Day 0	212	139	127	216	295	249	190	120	119	170
	Backlog	43	36	12	10	21	13	20	13	1	57
	Service level	83%	79%	91%	96%	93%	95%	90%	90%	99%	75%
Yard	**Pickers**	1	1	1	1	1	1	1	1	1	1
	Day 0	7	5	6	8	9	9	6	7	1	11
	Backlog	0	0	0	2	0	1	0	0	2	5
	Service level	100%	100%	100%	80%	100%	90%	100%	100%	33%	69%

Table 48. Capacity and service level during the second part of February 2022.

		15/2	16/2	17/2	18/2	21/2	22/2	23/2	24/2	25/2	28/2
Lifts	**Pickers**	2	2	2	2	2	2	2	3	2	2
	Day 0	353	552	347	164	213	711	212	545	241	499
	Backlog	2	2	111	3	3	75	0	14	2	1
	Service level	99%	100%	76%	98%	99%	90%	100%	97%	99%	100%
Pallets	**Pickers**	4	2	2	3	2	3	2	2	2	3
	Day 0	205	220	155	121	120	194	137	243	154	222
	Backlog	17	4	3	3	8	141	11	25	6	25
	Service level	92%	98%	98%	98%	94%	58%	93%	91%	96%	90%
Yard	**Pickers**	1	1	1	1	1	1	1	1	1	1
	Day 0	2	8	6	11	7	3	7	7	9	7
	Backlog	2	0	5	0	2	5	2	6	4	1
	Service level	50%	100%	55%	100%	78%	38%	78%	54%	69%	88%

4.4.2 Space Utilization

According to the interviews, the production warehouse has struggled with maximum space utilization for a long time. Two snapshots of the space utilization from the ERP system are shown in Table 49. This creates problems and inefficiencies. For example, the ERP system is supposed to find suitable storage locations for the received goods. However, with a maximum space utilization it means that the workers must manually find a location because there are no suitable locations left. Thus, SKUs are not placed at optimal locations and that affects the picking strategies. Items that are picked together frequently cannot be placed on the same shelf on the lifts. In addition, materials that have the same bin category cannot be placed close to each other, which increases travel time and the number of times you must change forklift.

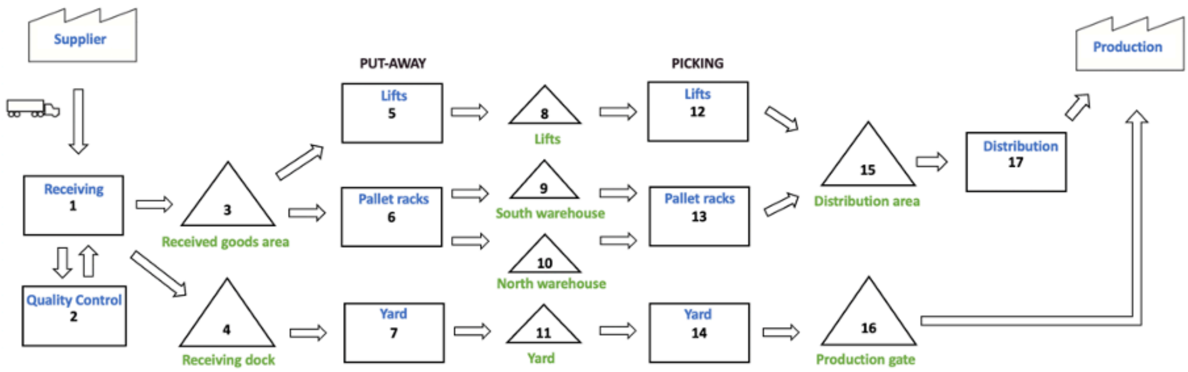
The interviewees also said that this was a result of the Covid pandemic because during the pandemic, there were many shortages of material. Thus, many machines had to be postponed and the material that was available for the postponed machines had to be stored in the warehouse. In addition, the production cannot produce any more machines than what they do now, and the sales continues to sale machines. Thus, the planning continues to be behind, and the space utilization continues to be at maximum levels.

Table 49. Two snapshots of the space utilization of the storage equipment.

Storage Type	**Storage Type Name**	**Number of storage locations**	**Utilization (%) 2022-03-02**	**Utilization (%) 2022-03-28**
120	Vertical lift HP	1880	95.05	96.60
140	Pallet HP	486	100	99.18
160	Cables, CIP & Shells	65	95.38	93.85
220	Vertical lift HT	1120	74.73	75.84
240	Pallet HT	435	90.11	92.90
320	Vertical lift BPU	2760	86.78	86.68
340	Pallet BPU	1169	94.95	94.52
440	Pull out units	286	94.41	95.49
600	Tube Automat & Cold Store	822	93.07	93.56
601	Tubes Outdoor Area	134	91.79	90.23
602	Yard	7	85.71	100
603	Cold Store Covered	1	100	100
604	Cold Store Closed	6	83.33	100
620	Vertical pallet lift	126	97.62	96.80
640	Pallet (Heavy)	90	97.78	100
643	Components Open area	77	98.70	98.70
644	Buffer stock	256	57.81	82.42

4.5 Value Stream Map

The data boxes of the current VSM in Figure 44 gives an overview of different data related to the material flow, which is based on previous subchapters, especially the activity profiling. It provides an indication of the current warehouse performance related to the picking. Since the focus is on put-away and storage, picking, and distribution, data related to those operations are shown. The blue boxes show data for the processes, while the green boxes show data for different inventory locations.



Put-away (Pallet)	
# of workers	1
# put-away per day	32 – 76 (54)
Avail time (min/day)	360
TAKT (min)	4.7 – 11.3 (6.7)
Time per put-away (min)	2.6

Put-away & Picking (Lifts)	
# of workers	2
# put-away per day	30 – 60 (45)
# picks per day	291 – 625 (458)
Avail time (min/day)	720
TAKT (min)	1.1 – 2.2 (1.4)
Time per pick (min)	0.5 - 2.8 (1.0)
Time per put-away (min)	1.3
Pick errors HP	187
Backlog Feb (days)	8/20

Put-away & Picking (Yard)	
# of workers	2
# put-away per day	3 – 13 (8)
# picks per day	6 – 18 (12)
Avail time (min/day)	720
TAKT	23.2 – 80.0 (36.0)
Time per pick (min)	5-60
Backlog Feb (days)	5/20

North Warehouse	
# of SKUs	1032
Days last movement	108
Utilization (%)	96

South Warehouse	
# of SKUs	2903
Days last movement	118
Utilization (%)	95

Lifts	
# of SKUs	5215
Days last movement	152
Utilization (%)	89

Yard	
# of SKUs	239
Days last movement	135
Utilization (%)	97

Picking (Pallets)	
# of workers	2
# picks per day	142 – 279 (210)
Avail time (min/day)	720
TAKT (min)	2.6 – 5.1 (3.4)
Time per pick	0.8– 9.7 (2.8)
Trucks per person	0.3– 0.6
Pick errors HP	50
Backlog Feb (days)	17/20

Distribution	
# of workers	1
Train avg load carrier per order	1
Stacker avg load carrier per order	0,8

Figure 44. The current value stream map of the warehouse.

The data for the lifts have been merged because the same two workers are responsible for both put-away and picking. Available time has been calculated as 6 hours per day times the number of workers since they have breaks and do other activities that is not picking and put-away. This has been used to calculate the takt, which is available time divided by number of put-away, picks or both. The number of put-away or picks is based on the averages and standard deviations from the empirical findings. The standard deviation has been added and subtracted from the average to show the variation, while the average is shown in the parenthesis. Also, truck per person is 0.6 because there are two trucks of each kind and at least three workers that deals with pallet put-away or picking, and all workers can require the same type of truck at once. In the worst case, meaning if service, deliveries, and distribution also wants the same truck, there are six workers with the same truck demand and that is 0.3 trucks per person. In addition, time per pick shows the minimum and maximum average based on the averages for different order types, while the parenthesis shows the total average. Lastly, space utilization are averages from the data on space utilization from 28th of March.

5. ANALYSIS & DISCUSSION

This chapter presents the data analysis and discussion of the study, which is based on the frame of reference and empirical findings. By applying theory to practice, it is possible to get a deeper understanding of the current state and how to improve its performance. The method described in the artifact has been used to do the analysis. Figure 45 show the part of the artifact that has been applied and how the different subchapters in the analysis and discussion relate to it.

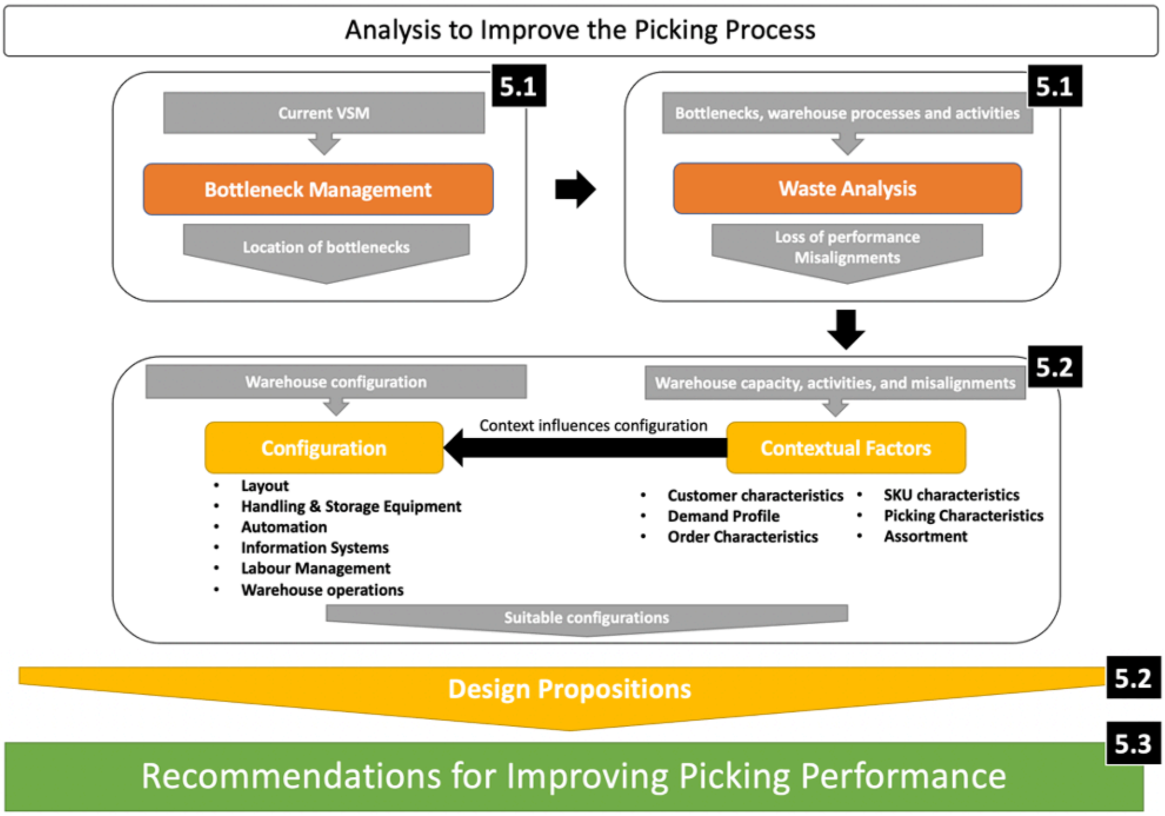


Figure 45. An overview of the structure in the analysis and discussion chapter.

The first subchapter begins with presenting the three potential bottlenecks that have been identified and their related wastes. The bottlenecks are the space utilization, pallet picking process, and the lift put-away and picking process. These are potential bottlenecks because different factors of the picking process vary, such as demand and capacity, which was shown in the empirical findings. The number of pick-lines that are created each day varies depending on which machine orders that are scheduled in the ERP system. Also, the number of pick-lines that can be picked each day differs, which is shown by the service level. Since the picking is done with human labour and not machines, the capacity varies more. The capacity is also influenced by what types of picks there are. For example, picks of heavy or large items can take longer time than smaller and lighter pieces. Thus, it can be hard to identify one constant bottleneck, which is common in manufacturing, and instead different potential bottlenecks have been identified.

Furthermore, the wastes contribute to inefficiencies of the bottleneck and need to be reduced to get the bottleneck resource to work at its maximum capacity. As mentioned in the frame of reference by King (2019), some wastes can be more unnecessary than others. Thus, the severity level of the wastes is going to be estimated based on how unnecessary they are and their impact. The levels that are going to be used are high (3), medium (2), and (1) low. A high level of severity means that the waste is entirely unnecessary and have a great impact on the performance, while a low level of severity means that it still contributes with value in some way or have less impact on the performance. By estimating the severity of the wastes, it is possible to get a picture of the performance losses of the bottlenecks due to misalignments of contextual factors and configuration.

The second subchapter continues with presenting the analysis about the different contextual factors of the warehouse that are related to the picking efficiency. This is about understanding how the contextual factors influence the choice of configuration, but also misalignments between them. The identified wastes are used as indicators for loss of performance and suggest that there is a better choice of configuration. The frame of reference chapter, as well as the empirical findings are also used to get a deeper understanding. Based on the analysis, propositions can be formulated that will provide guidance for designing solutions in terms of how to improve the picking performance. The propositions indicate how to achieve a certain outcome in a particular context by doing something that activates the mechanism that results in the outcome.

The third subchapter will discuss the practical implications that these propositions have on the case company and how they can reduce the wastes related to the bottlenecks. This involves understanding the current configurational elements and what needs to be changed to align with the contextual factors and increase performance. Thus, they are recommendations for how the case company can improve their picking performance.

5.1 Bottlenecks & Wastes

5.1.1 Space Utilization

The current value stream map indicates that a potential bottleneck in the material flow is the space utilization of the storage equipment. Figure 46 show that the space utilization is almost at maximum capacity, which means that there are no storage locations left.

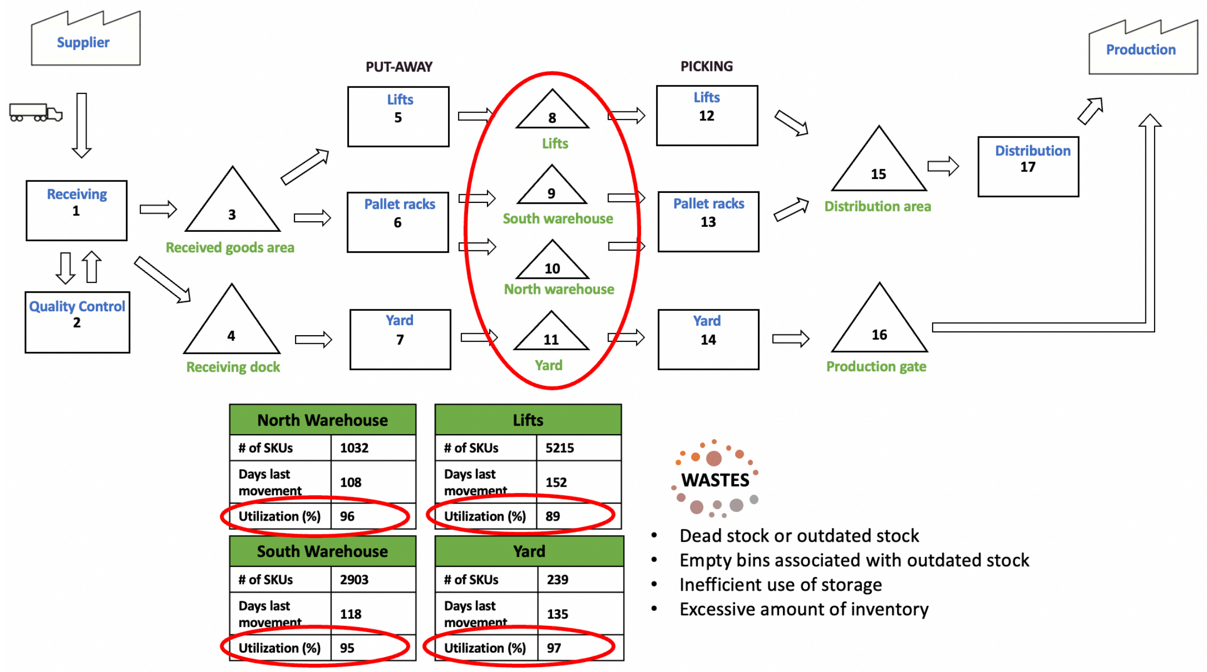


Figure 46. Potential bottleneck of the storage equipment.

The space utilization in the VSM is also the average between different storage types. Table 49 shows that some storage types are worse than others. A maximum capacity hinders efficient and smooth operations as there are no storage locations to place the received items. When the ERP system cannot find suitable storage locations for the received material, the workers at the inbound must manually place the material at locations that are not optimal. This affects the picking process because the pick density will be less. Thus, the space utilization becomes a potential bottleneck of the material flow in the warehouse, and it limits the picking performance.

There are different wastes that are related to the bottleneck, which are seen in Table 50. These wastes need to be resolved for the bottleneck to work at its maximum capacity. According to lean practices, inventory in general is often regarded as waste, which includes dead stock, outdated stock, buffer stock, and safety stock. Stock that has been stored for more than one year without any activity is regarded as dead stock. Table 33 show that there are 766 stored materials that have a last movement date from 2020 or earlier. This represents 7,9% of all the storage locations in the warehouse. This is considered as waste because the material uses storage locations and have no demand. Thus, they do not fulfil any function compared to buffer stock or safety stock. That is why dead stock is considered to have a high severity level and buffer stock is only considered as medium level. Dead stock also implies that some bins contain outdated materials. This is reasonable because purchasing can switch materials due to a new version or better supplier. As stated in the current state of the warehouse, this can mean that storage types with a dedicated storage policy, can have empty bins that are associated with outdated materials. This is also considered as having a high level of severity because it is just unnecessary waste.

Table 50. Wastes related to the space utilization.

Identified Wastes	**Description**	**Severity (1-3)**
Over processing	Storing SKUs inefficiently (not their primary bin type).	2
	Empty bins that are dedicated to outdated materials.	3
Inventory	Storing dead stock or outdated stock.	3
	Excessive amount of inventory (buffer stock and safety stock).	2

Also, Table 32 shows that there is a large difference between total number of stored materials and the distinct number, which can mean that the level of safety stock or buffer stock is too high. Table 49 indicate the level of buffer stock as there are 256 number of locations that are buffer stock and 82% of them were used in the end of March. However, difference between total number of stored materials and the distinct number can also suggest that SKUs are not stored in optimal types of bins. Instead of storing them in a larger bin, they are scattered all over the place. For example, Appendix E shows that materials have a primary bin, but have been placed in other bin types than the primary one. By storing materials manually in locations that are not optimal for them, it means that the storage equipment is not fully utilized. Another example of this is the number of smaller SKUs with low weights that are stored in pallets, which is indicated from Table 31 as there are many SKUs stored in the pallet racks in the south warehouse that have low weight. These can be stored in the lifts to better utilize the space. This waste is considered as having a medium severity level because it is not as bad as storing materials without demand. Yet, storing in an inefficient way does not give any value.

5.1.2 Pallet Picking Process

The picking related to pallets, meaning broken-case picking from pallets or picking of whole pallets, is another potential bottleneck identified in the warehouse with the help of the VSM. Takt time and time per pick or put-away gives indications on potential bottlenecks because takt time means the time interval that each item must be picked to exactly meet the demand. Figure 47 show that the average time per pick is below the takt time. However, both the number of picks per day and the time it takes to pick an item varies a lot. The VSM shows that it can happen that the time per pick is longer than the takt time, which indicates a potential bottleneck. Also, the backlog indicates that pallet picking has a problem with not finishing the pick-lines in time. The service level in Table 47 and Table 48 shows that pallet picking has a backlog 17 out of 20 days, which is more compared to the lift and yard processes.

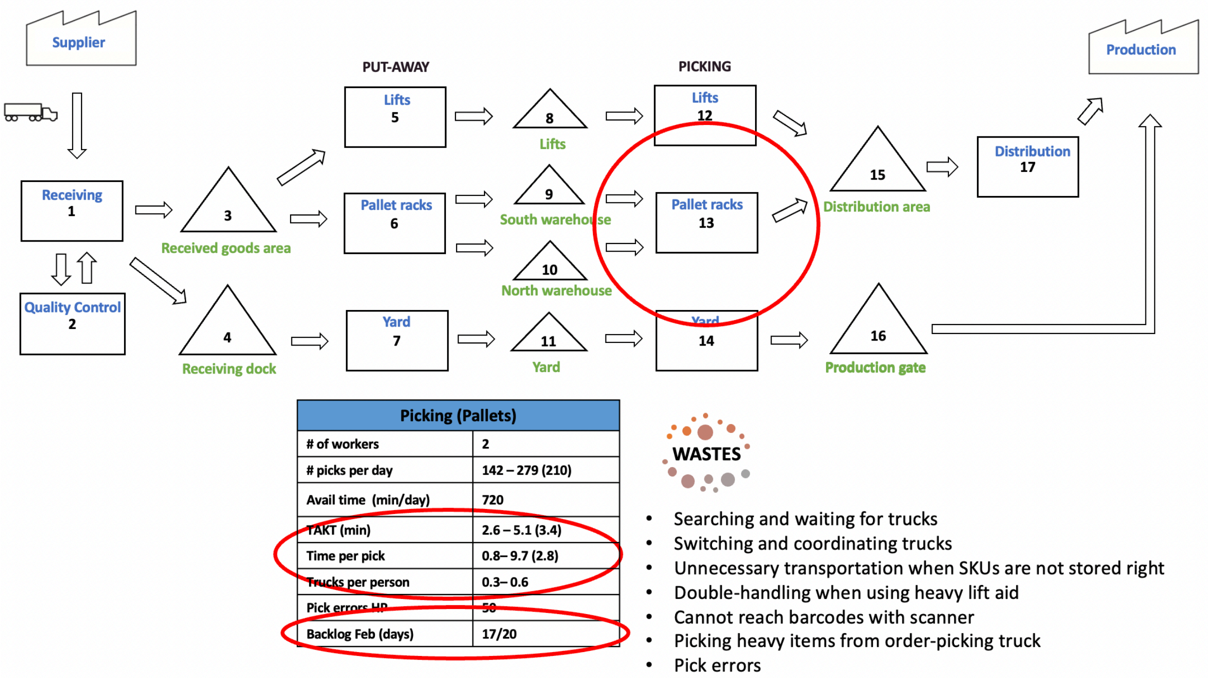


Figure 47. Pallet picking process as a potential bottleneck.

Furthermore, Figure 47 shows that there are not enough trucks per person in the pallet picking process. This is because there are two order-picking trucks and two reach trucks and the process involves several people sharing, switching, and coordinating between the trucks. The process also includes single picking, which means that the picker can require both types of trucks as an order can require both broken-case picking and whole-pallet picking. Furthermore, the picking team is not responsible for picking additional picks or deliveries, which means that service responsible and deliveries responsible can also need the trucks at times. It also happens that the distributor helps with the put-away, which means another worker that needs a forklift. Thus, several workers demanding the same type of truck results in a potential bottleneck.

There are also different wastes that are related to the bottleneck, which are summarized in Table 51. These unnecessary wastes are important to remove to get the bottleneck to work at a maximum capacity. Some of these wastes are a result of the first identified bottleneck, the space utilization as it affects the picking capacity. This is because material is not placed at their optimal location, which means less pick density. Table 39 shows that materials are picked from other sections that are not their primary section, which shows that materials are not placed where they are supposed to. It can also result in placing materials in the wrong zone as some zones are full, for example the storage types for HP material seen in Table 49. For the pallet picking this results in less pick density and therefore longer travelling, as well as more switching between trucks because material is not stored in their right storage section. Both these wastes are considered as a high level of severity because they do not contribute with any value and increase the time of the picking process a lot.

Table 51. Wastes related to the pallet picking process.

Identified Wastes	Description	Severity (1-3)
Waiting	Waiting for trucks when the required one is not available.	3
Transportation	Additional transportation when SKUs are not stored at their optimal locations.	3
	Switching between trucks.	3
Over processing	Double-handling (taking down pallets to pick pieces and place it back)	2
	Not being able to reach barcodes with scanner.	1
	Coordinating trucks between workers.	3
Motion	Picking heavy items when using the order-picking truck.	3
	Searching for trucks if they are not available.	3
	The information system suggests replenishment of material in a storage bin that is already full.	3
Defects	Pick errors.	3

There are also other wastes that were identified related to the pallet picking process. According to the interviews, there are especially problems with picking pieces from trucks due to bad ergonomics, especially when the items are heavy. This is considered as having a high level of severity because it can result in pain and sick leave of the workers, which was found as an issue based on the interviews. Also, items that weigh above 15kg that are picked as pieces should be taken down and be picked with the help of heavy lifting aid and then the pallet should be placed back. Since this is double handling, it is an unnecessary waste that takes time, but it is done due to better ergonomics, which is why it is rated as having a medium severity level.

Furthermore, the coordinating, sharing, switching between trucks are also considered as waste. When the required forklift is not available, it can result in waiting or rearranging the pick order, in other words postponing the picks. However, rearranging picks can increase the risk of pick errors. Furthermore, disruptions can also increase the risk of pick errors. Disruption can involve truck coordination with other workers while picking or another worker asking to get their pick for them. The severity level of the wastes related to the trucks, as well as the pick errors, are estimated to be of the highest level of severity because they are unnecessary wastes that takes time to fix, especially pick errors as it involves returns.

Another waste found based on the interviews, is that the information system wants to replenish material in a storage bin that is already full. This means that the worker is going to store the items and realises that it is full when reaching the bin. To solve this, the worker needs to tell the inbound, who finds a new location. Thus, this becomes double-handling and is a high level of severity due to being unnecessary and time-consuming. Lastly, it was found that the pallet pickers sometimes cannot reach the barcodes with the scanners, but this is considered as a low severity waste as it is easy to fix by confirming the pick-line on the computer.

5.1.3 Lift Put-Away & Picking Process

The last potential bottleneck that was identified with the help of the VSM is the put-away and picking processes at the lifts. It has the same reasoning as for the pallet picking, where the takt time can be shorter than the time per pick or put away, seen in Figure 48. However, the time per pick or put-away for the lifts varies less than for pallet picking, which can be seen on the variation as it only varies between 0.5 to 2.8 min for the lifts and 0.8 to 9.7 min for the pallets. This seems reasonable because a pick from the lift often looks the same, but a pallet pick can involve changing of trucks or getting a pick from the north warehouse, needing to take down a pallet and put it back, etc. This means that the bottleneck occurs less for the lifts than for the pallet picking. Furthermore, this is also shown when looking at the backlog in the VSM and the service level, seen in Table 47 and Table 48 because the lifts manage to pick their lines better than the pallets. Yet, the backlog highlights that the lift process is still a potential bottleneck because there are days where the capacity is not enough to meet the demand. In addition, the heat map, in Figure 32, indicates that there is a bottleneck at the HP lifts because the number of picks from them are unevenly distributed. Most picks are from the 48 and 49 lifts, and they do not have the twin function, meaning that they do not prepare the next shelf and therefore have longer waiting times between picks. Thus, there is a potential bottleneck when only having picks from lift 48 or 49 left as well.

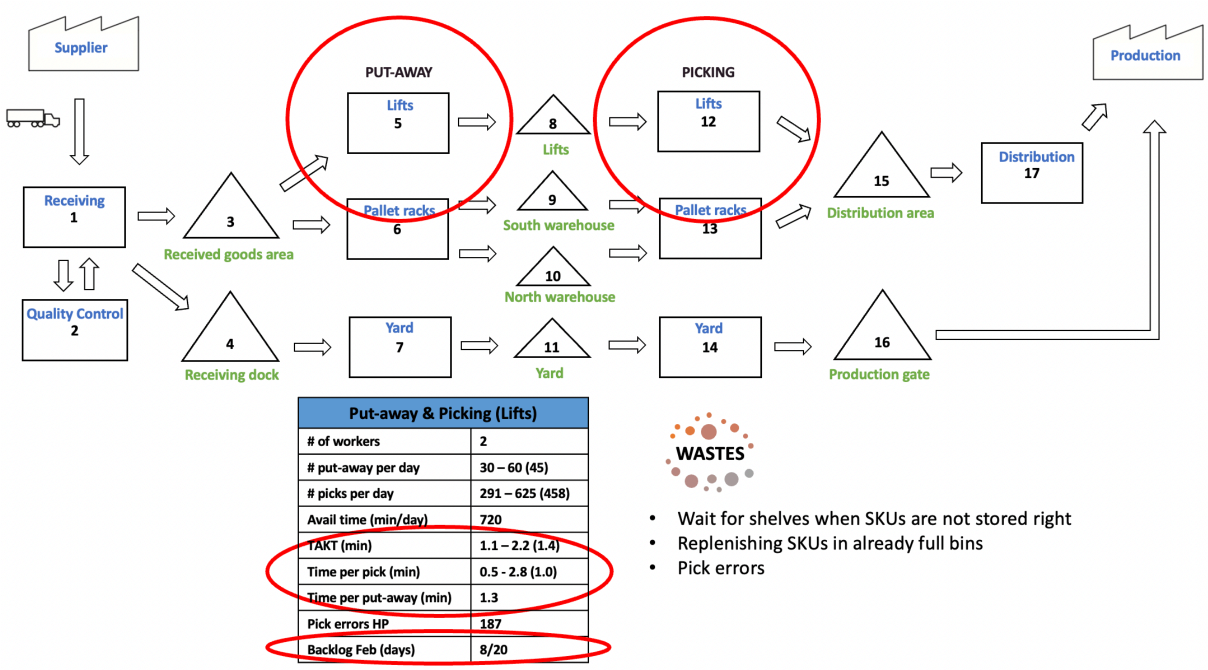


Figure 48. Potential bottleneck of the lift picking process.

The different wastes related to the bottleneck are summarized in Table 52. Some of these wastes are also connected to the first identified bottleneck, meaning the space utilization. As items are not stored at their optimal location it can mean that that there will be longer waiting time for the shelfs because items that are picked together are not on the same shelf. It can also result in picks from the wrong lift, meaning more switching between lifts and that can interrupt the work of the other lift picker. Furthermore, the material in the heavy lift is similar material as the other lifts, which is shown in Appendix F. This can also be seen as having SKUs not stored at their optimal locations as the heavy lift is slower than the other lifts because it can store whole pallets. This means that it is not used in the way it was designed for. Furthermore, how SKUs are stored in the HP lifts can also be considered as not having SKUs in their optimal locations because of the congestion at the 48 and 49 lifts. This is considered as having a high severity level as it is unnecessary and increases the picking time severely.

Another found waste, which is the same for the pallet process, is that the information system suggests replenishment of material in a storage bin that is already full. This results in double-handling as the put-away process needs to be done twice, which is time consuming and wasteful. Thus, the severity level is therefore the highest level. In addition, the empirical findings show that most pick errors occur at the HP lifts, seen in Figure 40 and Table 44. The pick is only confirmed with the pedals or computers, but there is nothing that tells the worker that they have picked the correct item. That is how picks are confirmed for pallet picking as they scan the barcode on the bin with the material to confirm. As a result, the risk of pick errors is increased for lift picking. Pick errors have a high severity level because it involves returns, which is time consuming.

Table 52. Wastes related to the put-away and picking of the lift.

Identified Wastes	Description	Severity (1-3)
Waiting	Wait for shelves as SKUs are not stored at their optimal locations.	3
Motion	The information system suggests replenishment of material in a storage bin that is already full.	3
Defects	Pick errors.	3

5.1.4 Summary of the Identified Wastes

The identified wastes of the bottlenecks have been summarized in Figure 49 based on what type of waste it is and its severity.

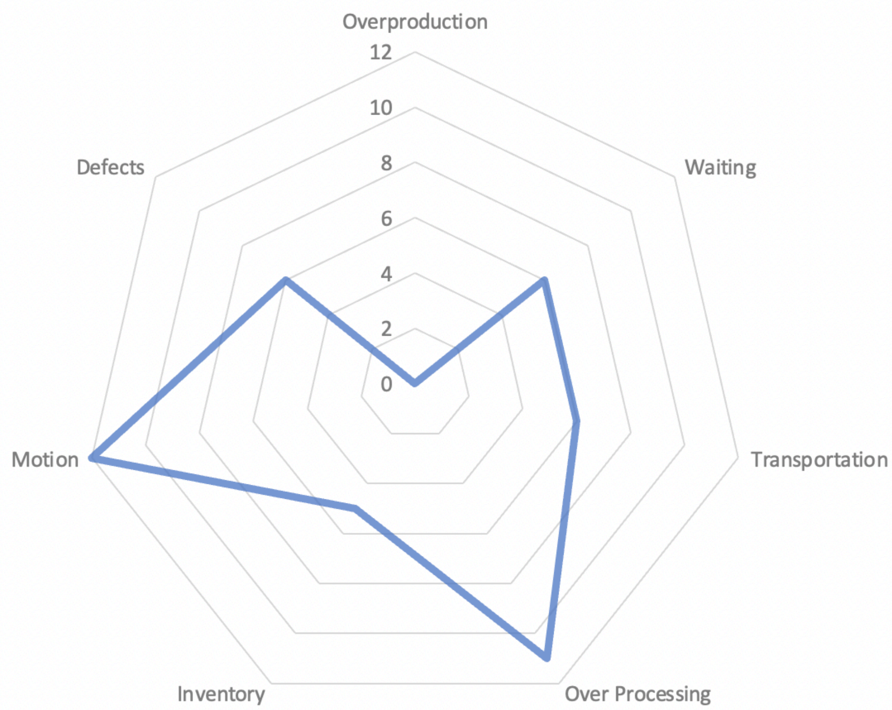


Figure 49. An overview of the identified wastes related to the bottlenecks.

The severity level of the wastes that are of the same kind have been added together to give a total score, which gives an overview of all the identified wastes and their impact. Motion and over processing were the wastes that have the largest impact. Waste related to overproduction was not identified. The rest of the waste types had a score of five or six. By approximating the severity of the wastes, it is possible to understand how solutions can impact and reduce the wastes levels. Thus, it gives an indication of how the picking performance will be improved by reducing the wastes from the bottleneck resources.

5.2 Contextual Factors

There are different contextual factors in the warehouse that have been identified, which are summarized in Table 53. The customer characteristics of Tetra Pak means that they produce customized machines of several types that are in divided into three product categories: BPU, HP, and HT. As a result, the warehouse aims to consolidate and store all materials needed for producing these machines. This naturally affects other contextual factors such as product characteristics, order characteristics and process characteristics. Producing advanced machines requires SKUs of different sizes and weights. Also, the organization need material for around 50 machine types, thus there is a high volume of SKUs, and the warehouse activity is distributed between them. This also includes that assortment often changes due to customized machines with special stock, materials from new suppliers, materials for new machines, changes in demand, etc. Furthermore, the process characteristics includes different picking methods as there are different weights and sizes of the materials. The order characteristics in terms of order sizes will also vary as machines are customized and the production involves producing different types of machines that are manufactured in different stages. Production also means that there is a time constraint for finishing the picks as the production is dependent on the material and everything needs to follow the schedule.

Table 53. The contextual factors identified at the production warehouse.

Level	Contextual Factor	Description
Business level	Customer characteristics	Businesses in the liquid food and beverages industry requiring processing machines. Customization is important due to different processing requirements depending on the food or beverage.
	Demand profile	No seasonality except summer or winter during holidays. Variations in pick-lines changes every day.
SKU level	Product characteristics	Different sizes and weights of the SKUs. SKUs based on different product categories.
	Assortment	High number of distinct SKUs in the warehouse and new materials are introduced frequently.
	Volume	High volume of SKUs and variations in popularity.
Process level	Order characteristics	Different order types and varying number of pick-lines per order.
	Process characteristics	Picking of whole pallets and broken-case picking. Requires different types of forklifts, storage types and pick zones. Consolidation is required before distribution. Time constraint.

As the contextual factors influence each other, they can be categorized into different levels seen in Table 53 and Figure 50. The first level is the business level that includes the customer characteristics and demand profile that reflects the purpose of the business and warehouse. This naturally affects the SKUs stored at the warehouse, which means the product characteristics, assortment, and volume. Thus, the next level is the SKU level. The different sizes and weights of the SKUs influences the process level because it affects the choice of handling and storage equipment, which also means the picking methods. Lastly, the previous levels determine the level of complexity. As a result of the varying contextual factors, the complexity of managing the warehouse increases because the choice of configuration needs to align with many different situations, which is seen in Figure 50.

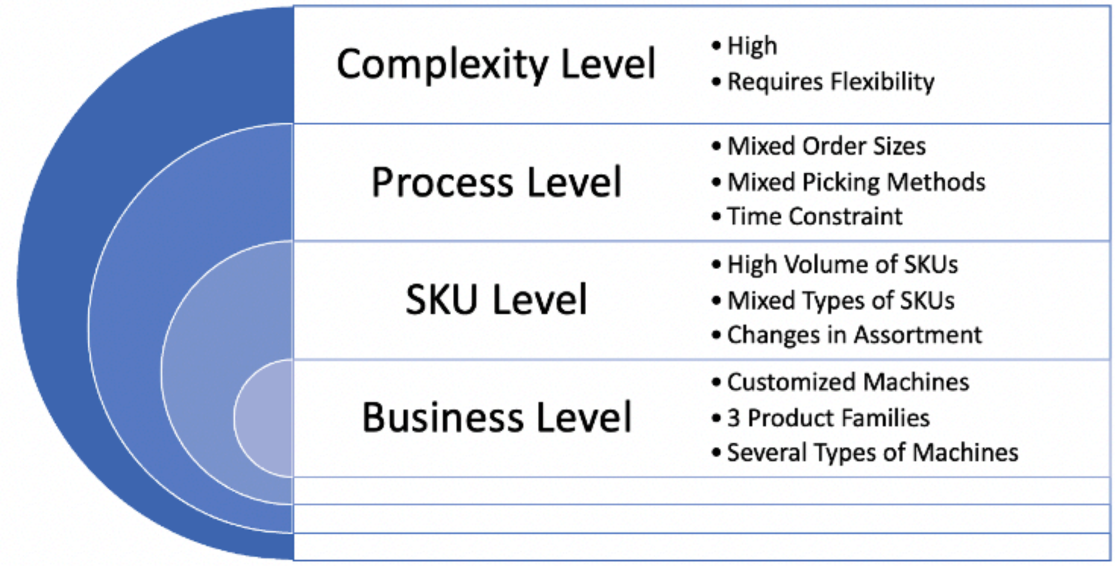


Figure 50. The different levels of the contextual factors and how they affect complexity.

Based on the different contextual factors in the warehouse and their characteristics, as well as the rest of the empirical findings and prior theory, it is possible to investigate how the context influence the choice of configuration. It is also possible to understand misalignments between the context and configuration with the help of the identified wastes. This analysis will be summarized through propositions that can be used to understand how to align configuration with context to increase performance. Thus, these can be used to remove wastes and improve picking performance.

5.2.1 The Volume of SKUs & Warehouse Activities Determines the Layout

The empirical findings show that there is a high volume of SKUs as the warehouse have 6385 distinct number of materials stored in the warehouse. It also shows that the warehouse activity is divided between many different SKUs, which can be seen in the heat maps (Figure 32 and Figure 33) and the percentage of all picks that the top 15 picked materials represent (Table 36). The heat maps show that there are many locations that are frequently picked from as they have a red or yellow colour. The top 15 most picked materials from the lifts represent almost 6% of all picks from the lifts between September 2021 to February 2022. For the south warehouse, the number is 8%. These are also the areas that have most pick-lines (Figure 39). However, the top 15 most picked materials from the north warehouse represent 28% of all picks from the north warehouse. This means that the activity is concentrated to a fewer SKUs in the north warehouse. This is also seen in the heat map as the floor storage have most picks. The warehouse has a layout that is aligned with this characteristic, which is illustrated in Figure 51.

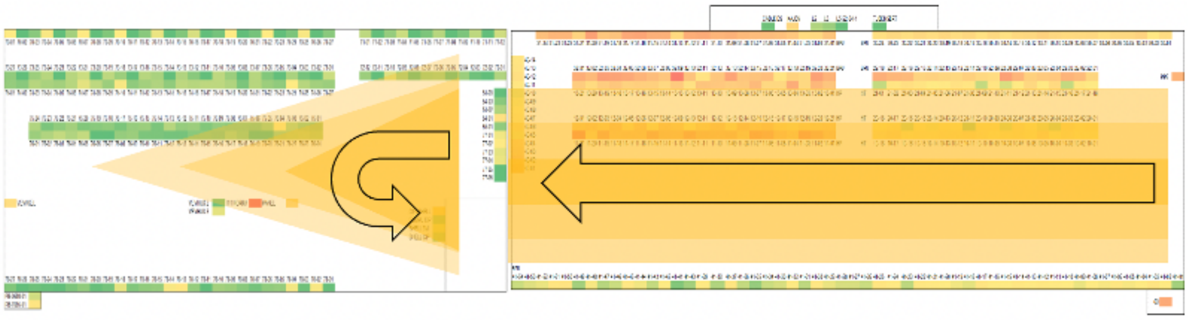


Figure 51. U-flow configuration in the north warehouse and flow-through configuration in the south warehouse.

As mentioned in the literature by Bartholdi & Hackman (2019), a flow-through configuration is suitable when there are high volumes of SKUs in the warehouse and a U-flow configuration is more suitable when the activities are concentrated to a few SKUs. As the south warehouse have a high volume of SKUs and the activities are divided between many of them a flow-through configuration is more suitable. This configuration is what the current south warehouse has because the receiving is in one end and the outbound area that is mostly used is on the other end. The result from this choice is that there will be many convenient storage locations and less traveling as the activity revolves around many SKUs. Furthermore, the north warehouse uses a U-flow configuration because the same door is used for inbound and outbound, which is suitable as the activities are mostly concentrated to the floor area that is close to the entrance and exit. This will shorten the travelling done to get the SKUs. The case study did not find any wastes related to the configuration, which suggests an alignment between configuration and context. Based on this, following proposition have been formulated:

Proposition 1: *To increase the picking efficiency in a warehouse where warehouse activities are shared between many SKUs, a flow-through configuration should be used to minimize travelling.*

Proposition 2: *To increase the picking efficiency in a warehouse where warehouse activities are shared between few SKUs, a U-flow configuration should be used to minimize travelling.*

5.2.2 Variations in Assortment Requires Collaboration & Maintenance

The warehouse does not only have a large assortment, but an assortment that fluctuates and changes. This is a result of producing customized machines of different types, which requires purchasing to buy many different types of materials depending on what is going to be produced. Figure 31 in the empirical findings section shows that the warehouse has received many new materials that have not been registered in the system yet between September 2021 to February 2022. Furthermore, Table 33 displays that there are in total 149 materials that is considered special stock, meaning that it is connected to a specific machine order and can only be picked for that order. The table also shows that there are dead stock in the inventory, meaning materials that has been stored for over a year without any activity. This is also an indicator of how the assortment changes as materials becomes outdated. Furthermore, the dead stock was identified as a waste, which suggests a misalignment between the context and configuration.

The empirical findings suggests that a lot of the wastes related to the inventory are a consequence of the lacking communication between the different departments: warehousing, purchasing, and order, seen in Figure 52. For example, the lack of communication can result in dead stock because sales can change materials in an order after purchasing has acquired the material. When sales do not inform this to purchasing, both the old and new material is delivered to the warehouse, where the old material is never used and just stored in the warehouse. Table 33 shows that there is special stock that had a last movement date in 2019 and 2020, which means that the machines have already been produced. This is implied because the special stock from 2020 have no demand. Thus, these can be examples of how orders have been changed but the old material is still stored in the warehouse without demand. Another example is that purchasing can switch out standard material to a new one because of a new version or a new supplier. However, the old material is not used up and is still stored in the warehouse. This results in outdated material without demand in the inventory.

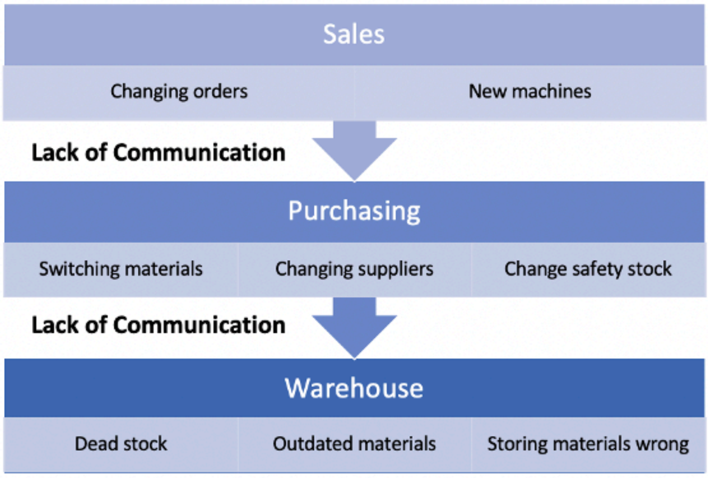


Figure 52. How sales and purchasing can affect the assortment and how it can affect the warehouse.

Furthermore, the lack of communication can also result in materials not getting the optimized storage location because changed purchasing strategies such as the amount of buffer stock or safety stock. For example, total number of stored materials is 9202 and the distinct number of materials is 6385, shown in Table 32. The large difference between total number of stored materials and the distinct number of materials can indicate that safety stock has increased but the storage bin is the same. Instead of fixing a larger bin for the material, the material is instead stored at several places. Another indication of this is from Table 39 that shows the 15 most picked materials from the pallet racks in the south warehouse. Many of these have the wrong definition as they are the most frequently picked materials, yet they are defined as having the storage section M01 instead of H01 that indicates popular SKUs. Purchasing should have a sense of what materials that are popular and not, which is useful information for the warehouse. However, this also shows that the warehouse lacks maintenance of their inventory as they are responsible for the storage policies of the information system.

Changing purchasing strategies and lack of communication can also affect dedicated bins in terms of having bins dedicated to material that is not purchased anymore. For example, the storage type 440, the pull-out units, should store popular and heavy SKUs. However, the empirical findings show that some locations from 440 have barely been picked from (Figure 34). This can also be a result of altered purchasing strategies and communication flaws, but also lack of maintenance from the warehouse side.

Dead stock and outdated stock were identified as a waste, as well as storing SKUs inefficiently, and having empty bins dedicated to outdated materials. This points at misalignment between context and configuration. The analysis, which is summarized in Figure 53, suggests that the poor performance is due to large variations in the assortment and the lack of communication between departments in the organization, as well as lack of maintenance of the inventory. Communication is needed to avoid wastes in the inventory when the assortment changes.

Maintenance is needed to get rid of already existing wastes in the inventory after the assortment has changed.

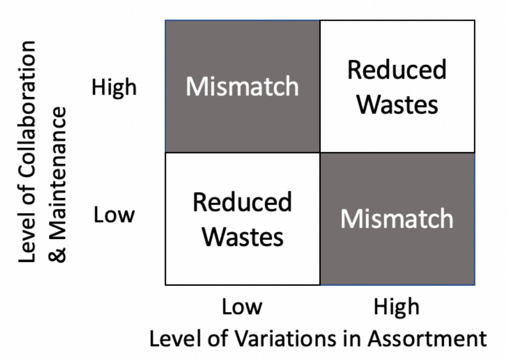


Figure 53. How to match level of variations in assortment with level of collaboration and maintenance according to the empirical findings.

Figure 53 indicate that high level of variations in assortment needs to either have a high level of collaboration and maintenance or decrease the level of variations in assortment to reduce wastes. A low level of variation in assortment means that there is a low complexity and stability in the system. For example, this can refer to a situation where standardized products are manufactured that only requires a few identical materials and where demand is stable. This means that purchasing strategies change less and there is a lower risk for wastes entering the inventory. Thus, there is a less need for collaboration between departments regarding the inventory and less need for the warehouse to regularly examine the inventory. If the level of collaboration and maintenance would be high when the level of variations in assortment is low, this would mean a mismatch between context and configuration because it is inefficient use of resources. Based on the discussion above, following propositions have been formulated:

Proposition 3: *To increase space utilization and efficiency in a warehouse with changing orders and purchasing strategies, sales and purchasing needs to establish a procedure for informing each other and the warehouse management when orders or purchasing strategies changes to adjust the inventory.*

Proposition 4: *To increase space utilization and efficiency in a warehouse with changing orders and purchasing strategies, the warehouse management need to regularly examine the inventory to remove inefficiencies and maintain efficient utilization of the storage equipment.*

5.2.3 Product Categories & Picking Process Facilitates a Family Grouping Storage Policy & Cross-Aisles

To simplify the complexity of dealing with many different machine types, the organization has divided the products with similar characteristics into three different families: BPU, HP, and HT. Thus, the production is built around those, which affects the warehouse as each order have an unloading point that is associated with one product category, seen in Table 40. Also, because the product families differ from each other, the SKUs needed will mostly differ. Thus, the warehouse has also built its processes around the three product families. Table 26 shows the different storage types in the warehouse, which clearly indicates that some of the pallet racks and lifts belongs to a specific product group. The layout in Figure 54 shows which of the pallet racks in the south warehouse that is dedicated to either BPU, HP, or HT.

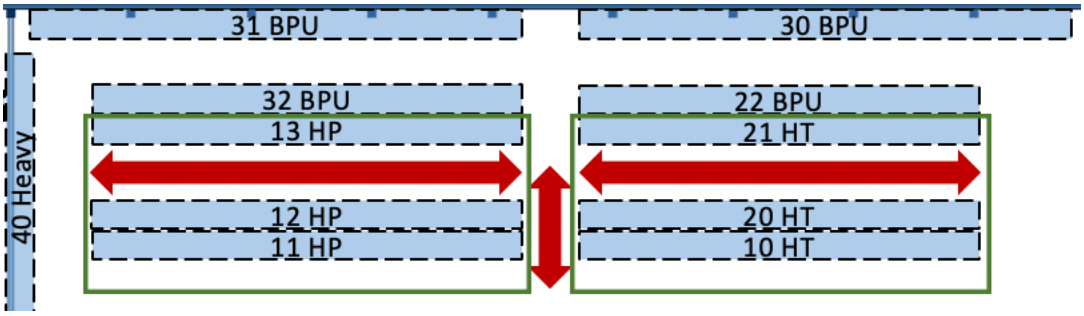


Figure 54. Layout of the south warehouse that highlights the zones with family grouping and its cross-aisles.

Furthermore, the layout in Figure 54 show that the different zones have been separated with a cross-aisle. This is beneficial as it enables movement between storage locations, and therefore reduces travelling according to Bartholdi and Hackman (2019). The empirical findings show that this is especially suitable for zones where multiple items are going to be retrieved because it groups together material of the same family group and enable movement between storage locations, as well as in and out of the zone because there is an exit in the end of the zone, which is seen in the layout. Thus, the choice of family grouping is suitable as both orders and SKUs can be divided after product categories, and cross-aisles can be used to divide the zones and decrease travelling for multiple picks.

No wastes have been identified related to the choice of family grouping and cross-aisles, which suggests that it is suitable and increases performance. This is also aligned with the literature as Bartholdi and Hackman (2019) highlight that related SKUs that must be stored together are called a product family and it can result in less traveling and better space utilization. This can also be identified as a type of class-based storage method, where SKUs are categorized according to their product family.

However, family grouping is only used in the south warehouse for the pallet racks and the lifts, but not for the north warehouse or the yard. As the north warehouse only includes picking of whole pallets, there is no point of having family grouping because each pick needs to travel back and forth from the distribution area or production to leave the pallet. Thus, items cannot be picked together at once. Family grouping is also not used for the lift 62 in the south warehouse that has broken-case picking. As the stored material in the lift 62 is not optimal, this was identified as a waste. This can be explained as a misalignment between configuration and context. Furthermore, the pallet rack 41 in the south warehouse uses a family grouping, but it stores material that is picked as whole pallets. However, this can be explained as these materials have more activity than materials in the north warehouse, which is seen in the heat map in Figure 33. This is suitable because then they are close to the distribution area. This just happens to be BPU items and if other materials had higher warehouse activity, it would be more suitable to have them there.

Following propositions have been formulated based on the discussion above:

Proposition 5: *To increase the picking efficiency in a warehouse with broken-case picking and where orders and SKUs are divided based on product families, a family grouping storage policy should be used to keep related SKUs together.*

Proposition 6: *To increase the picking efficiency in a warehouse with zones and broken-case picking, cross-aisles at the end of the zone can decrease traveling as it enables movement between storage locations, as well as in and out of the zone.*

5.2.4 Variations in SKU Characteristics Defines Warehouse Equipment & Zones

Furthermore, advanced customized machines involve different types of SKUs in terms of varying size and weight, which means that the warehouse need to handle that matter. Thus, this characteristic influences the choice of handling and storage equipment. To begin with, the warehouse uses lifts, pallets, and floor storage. Table 31 show the weight distribution of the SKUs and where they are stored. Small items with low weight are stored in lifts, which is suitable as lifts takes advantage of the vertical space and allows faster picking, which is seen in Table 40 because picks from the lifts are faster than picks from pallets. Also, Table 47 and Table 48 shows the service level and it displays that it is possible to pick more pick-lines per day from the lifts than from the pallets. Furthermore, larger items, which usually means heavier items, are stored at the north warehouse floor storage or at the yard. This is suitable as the material can be too large to be stored in racks. Materials that are of small or medium size with varying weights are stored in single-deep racks. This is suitable because racks utilize the vertical space, and each pallet is independently accessible. As the contextual factors of the warehouse varies, it is important to keep the warehouse as flexible as possible, which makes single-deep racks appropriate. Also, as the assortment changes a lot, it can be hard to determine a suitable lane depth.

Table 54 summarizes how the weight and size affects which storage equipment that is suitable. The warehouse choice of storage equipment is also supported by the literature, based on Table 11, Table 14, and Table 16 which present suitable contexts of the different storage equipment .

Table 54. How weight and size influence the choice of storage equipment.

		Size		
		Small	**Medium**	**Large**
Weight	**High**	Lift/Pallet	Pallet/Floor	Floor
	Medium	Lift	Pallet	Floor
	Low	Lift	Pallet	Floor

Furthermore, the warehouse is divided into different picking zones, which are seen in Figure 55. This means that some pickers are responsible for the lifts, some for the pallet picking, and some for the yard. Thus, the zones are mainly based on the different storage equipment. However, there is also floor storage in the pallet zone, but floor storage can be regarded as a pallet rack with only one level. Also, there is a difference between the floor storage method in the pallet zone and in the yard as the floor storage in the pallet zone is inside compared to the floor storage in the yard, which is outside. It is possible to have zones based on storage equipment because SKUs can be categorized according to their weight and size, and this influences the choice of storage equipment. They can also be categorized based on their sensitivity. For example, larger materials that have electrical components need to be stored on the floor storage in the north warehouse. By dividing the warehouse into zones based on storage equipment, the picking operation becomes more efficient. Table 18 highlight that it is suitable to use zone picking when picking from different areas. This results in less traveling and congestion, as well as getting pickers familiar with the items in the zone and get more accountability.

	Zone Pallet	Zone Lift	Zone Yard
SKU Size	Small, Medium, Large	Small	Large
SKU Weight	Low, Medium, Heavy	Low	Heavy
Storage Method	Floor (inside), Pallet	Lift	Floor (outside)
Picking Method	Broken-Case, Whole Pallets	Broken-Case	Whole Pallets
Handling Equipment	Order-Picking Truck, Reach Truck, Counter-balanced forklift	Lift	Counter-balanced forklift

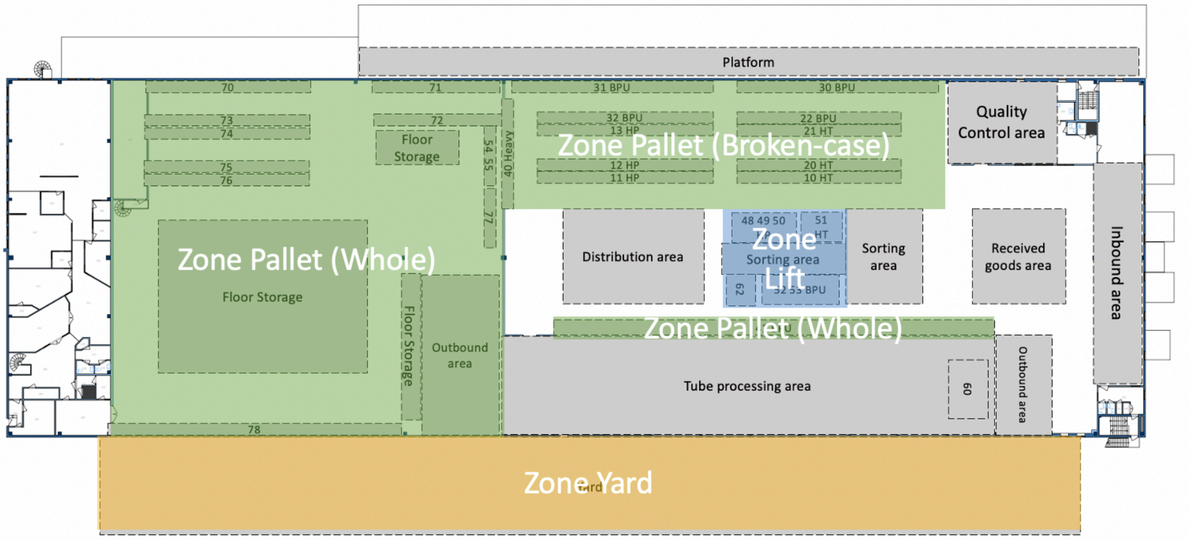


Figure 55. The different current pick zones of the warehouse.

The empirical findings show that the picking zones is only used by the picking team and the yard workers, which is seen in Figure 56 that illustrates the different workers and the processes related to the picking zones. The picking team and yard team are responsible for the daily orders that goes to the production. Service is responsible for additional picks due to pick errors, while deliveries deal with orders that goes directly to the customers. They retrieve the items themselves from the lifts and pallets but give the pick-lines to the yard if the items are going to be retrieved from there. Figure 56 also shows that the pallet workers have someone responsible for put-away but for the lift and yard, all the workers are responsible for both put-away and picking.

The fact that picking zones is not used by service and delivery, does not indicate that picking zones are not suitable. Some wastes that were identified related to the picking process, was the switching and sharing between trucks. As service and delivery also need the forklifts during their picking process and contribute to the wastes, it indicates that there is a misalignment between configuration and context. Since zones are suitable when picking from different areas (Table 18), service and delivery should also use a zone picking strategy. However, to avoid congestion between the picking team, service, and delivery, the pick-lines of service and delivery should instead be picked by the picking team and yard.

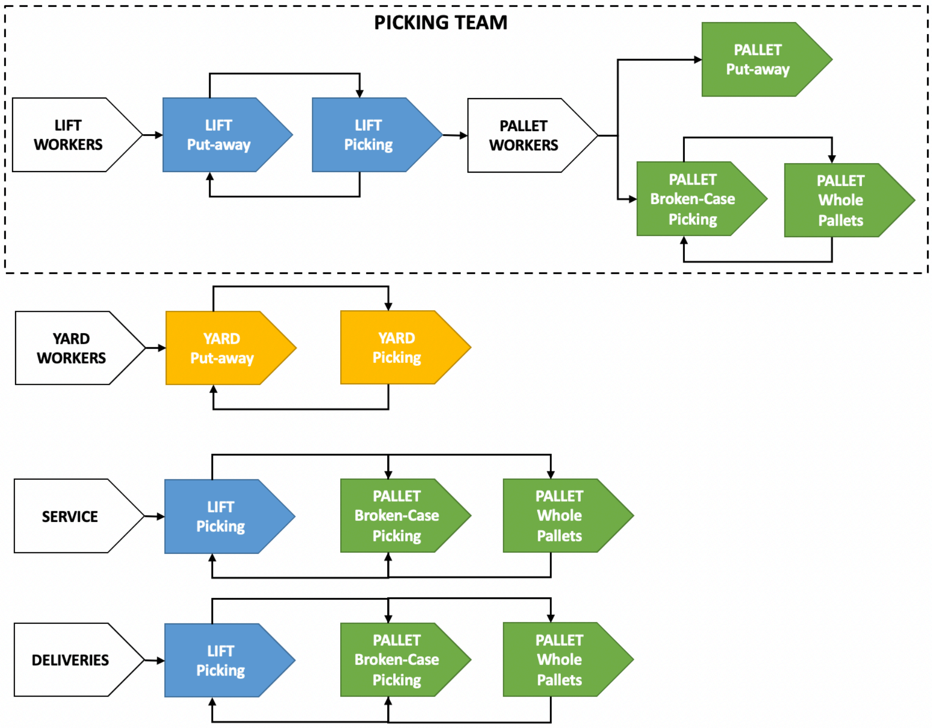


Figure 56. Workers and processes related to the picking zones.

Varying SKU characteristics also influences the choice of handling equipment because different handling equipment have different purposes, see Table 55. Figure 55 also indicates which forklifts are used in the different zones. The current state of the warehouse shows that order-picking trucks are used for broken-case picking, meaning SKUs that have low or medium size and varying weights. Furthermore, larger items that have one item per pallet uses the reach truck. However, the reach truck is also used for taking down heavy pallets where many items can fit the pallet, meaning L01 pallets, and pallets that are on the highest level of the rack. Counterbalanced forklift is used for very heavy or large materials.

Table 55. When and where different types of forklifts are used.

Forklift	**Where**	**When**
Order-picking truck	Pallet racks in the south warehouse except rack 41, L01 storage sections, and highest level of the pallet rack.	Broken-case picking from pallets with items below 15kg.
Reach truck	North warehouse, rack 41, storage section L01, and highest level of the pallet rack.	Whole pallets, heavy SKUs, or SKUs stored far up.
Counterbalanced forklift	North warehouse for heavy materials, yard.	Heavy SKUs.

To minimize switching, coordinating and sharing between trucks, the warehouse has divided up broken-case picking to one area and the picking of whole pallets to another. Due to different storage types, the pallet pickers will first do the broken-case picking and then the whole pallets picking. This highlights the importance of dividing the warehouse into different areas based on handling equipment. However, since switching, coordinating, and sharing between trucks were identified as wastes, it points at a mismatch between configuration and context. Similar as having areas based on storage equipment, areas based on handling equipment should also utilize zone picking. Thus, the waste from switching trucks is based on the misfit from having broken-case pallet picking and whole picking as one zone. Another example that highlights the importance of having zones based on handling equipment is the yard, where only the counter-balanced forklift is used. This avoids switching between forklifts and makes the process more efficient.

Furthermore, the warehouse uses the storage sections L01, M01, and H01, which are described in Table 28. Pallet racks are divided into different storage sections, meaning that one part of the racks for the same storage type is L01, another part is M01, and a third part is H01. This is to minimize the switching between trucks during picking. However, due to a maximum space utilization and lack of free storage locations this approach fails at times. This is also connected to the waste related to the sharing between trucks, which points at a misalignment. The misconfiguration is a result of not having the picking zones entirely divided based on handling equipment as the pallet picker can require both trucks. Yet, as the warehouse tries to have different sections to minimize the switching between trucks, it shows the importance of categorizing SKUs to areas based on their characteristics and what handling equipment is required.

Thus, dividing the warehouse into zones based on the handling equipment is also suitable because it makes the process more efficient since there will be less travelling and switching between forklifts. As both handling and storage equipment are similarly influenced by the SKU characteristics, it is possible to have warehouse areas based on both. The following proposition have been formulated based on the discussion about handling and storage equipment:

Proposition 7: *To increase picking efficiency in a warehouse with varying SKU sizes and weights, a class-based storage policy based on the required handling and storage equipment can be used to simplify the workload and processes.*

The weight also influences the location of the material in the storage equipment. Storage type 440, which are the pull-out units in the pallet racks, is supposed to have heavy materials that are frequently picked. This means items that are below 15kg as they should be possible to be picked without aid, but still heavy because picking these items from the order-picking truck is not ergonomic. Thus, these items should be in pull-out units since they are at the lowest level and avoids twisting and reaching, which is necessary when using the order-picking truck. Bad ergonomics due to heavy lifting from the order-picking trucks was also identified as a waste, which highlight the importance of aligning the configuration to the contextual factor as it impacts the performance. Furthermore, this is suitable with a volume-based storage method because by having the heavy items that are mostly picked means better ergonomics for the pickers. This has resulted in the following proposition:

Proposition 8: *To increase picking efficiency in a warehouse with broken-case picking involving heavy materials, heavy materials that are frequently picked should be stored at easily accessible locations to get better ergonomics.*

5.2.5 Order Characteristics & Picking Process Affects Batching & Routing

Different types of customized machines result in order characteristics that vary in terms of number of pick-lines and unloading point. Table 40 show the different orders based on unloading points and how pick-lines can differ between them for the lift picking and pallet picking. Some orders only have a few pick-lines, and some have many. Furthermore, orders for the same unloading point fluctuates as well, which is seen in Table 41. Table 42 also show that even the same machine type does not have the exact same number of pick-lines, which is a result of having customized machines.

According to literature, in Table 18, single picking is suitable for large orders and batch picking is suitable for smaller orders, but batching can also be beneficial for very large orders with small items. The empirical findings show that batching sometimes occurs at the lifts even though the SOP says that they should do single picking. They batch orders that have the same unloading point because that means that the same lifts will be utilized as they are divided per product family. Due to the variations of orders, they batch more orders for smaller orders and batch less order for larger orders, which is aligned with the literature. This is to increase the efficiency by increasing the pick density. As there is also a time constraint at the warehouse, it is appropriate that they only batch a few large orders to get them done in time. If too many orders are batched, there is a risk that several orders can be half finished at the end of the day. It is also appropriate to batch at the lifts because it is possible to have several load carriers at the lifts, which simplifies batching and sorting. This is harder for pallet picking because when broken-case picking they only have one pallet and batching is not possible for whole pallets as they can only take one pallet on the reach truck. Thus, it is only suitable for pallet pickers to batch when it is broken-case picking and orders are small. Figure 57 illustrates when the different methods are appropriate based on order size and load carrier capacity.

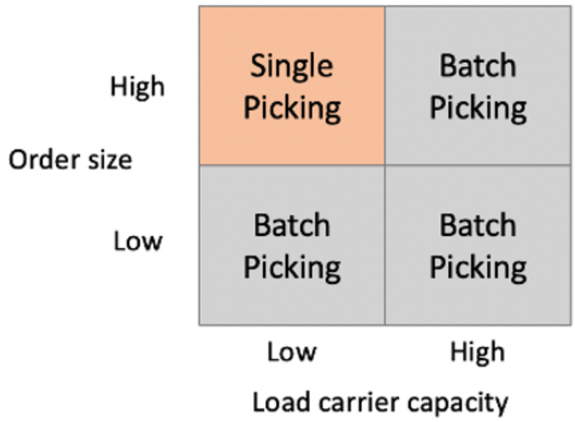


Figure 57. When single picking and batch picking is appropriate based on the order size and load carrier capacity according to prior theory and empirical findings.

Based on the discussion above, the following proposition have been developed:

Proposition 9: *To increase picking efficiency at the lifts where SKUs are small and load carrier capacity is high, orders with picks from the same product category should be batched picked to increase the pick density.*

Proposition 10: *To increase picking efficiency at the lifts where batching occurs, order size varies, and there is a time constraint, the number of batched orders should be higher for smaller order than for larger order to increase the pick density and get orders done in time.*

Proposition 11: *To increase picking efficiency at the pallets where broken-case picking occurs, order size varies, and load carrier capacity is low, single picking should be used for large orders and batch picking should be used for small orders to increase the pick density.*

Furthermore, variations in order characteristics affects routing. Table 19 in the literature section presents the different routing methods, where some are suitable for larger orders, and some are more suitable for smaller orders. Thus, mixed orders sizes, makes it hard to determine a suitable routing strategy. The empirical findings show that the warehouse uses a transversal routing method as pick-lists are printed out based on the storage location number in an increasing order and because of the layout of the pallet racks. Figure 58 indicate with the arrows how the storage location number increases and therefore the routes used.

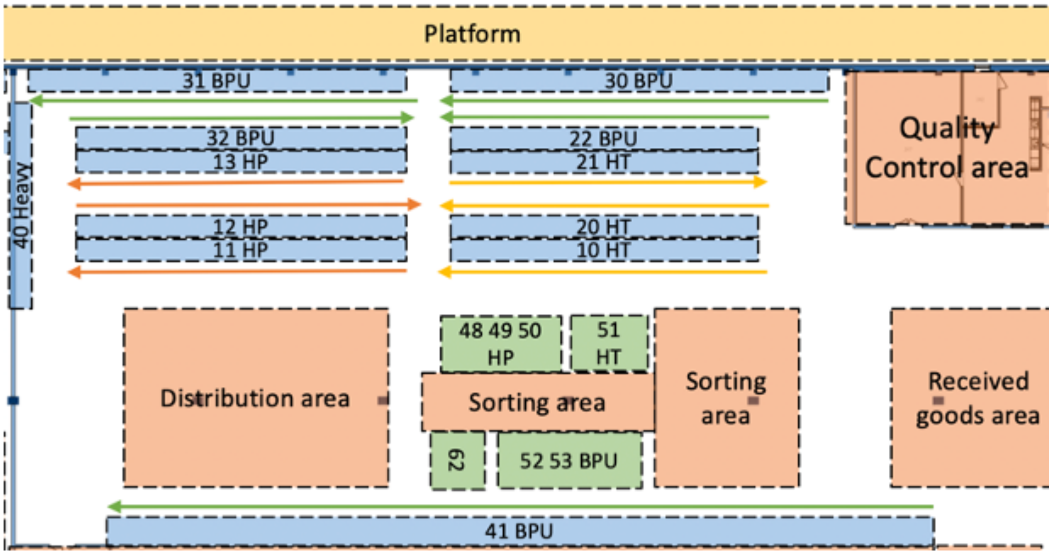


Figure 58. Layout of the south warehouse and how storage location number increases.

According to literature, the best routing solution would be an optimal strategy, which is also suitable for mixed orders as it is hard to determine what heuristic method to use. However, as the warehouse only have few aisles per zone as shown in Figure 58, they utilize the transversal method because of its simplicity and an optimal strategy might not be worth the trouble. Also, no wastes were identified, which does not suggest less performance. The frame of reference includes the article from Petersen and Aase (2004), where they highlight that switching from transversal to optimal routing reduces travel, but significantly less than changing picking or storing policies. The authors also stress that the transversal strategy is still considered acceptable because it is the easiest to use and can avoid confusion and errors that comes with the optimal strategy. Thus, the following proposition has been formulated:

Proposition 12: *To increase picking efficiency in a warehouse where order size varies and the picking only involves a few aisles, a transversal routing method is considered acceptable due to its simplicity and less risk of confusion and errors.*

5.2.6 Summary of the Propositions

Figure 59 summarizes the propositions that have been developed in the subchapter based on the different contextual factors.

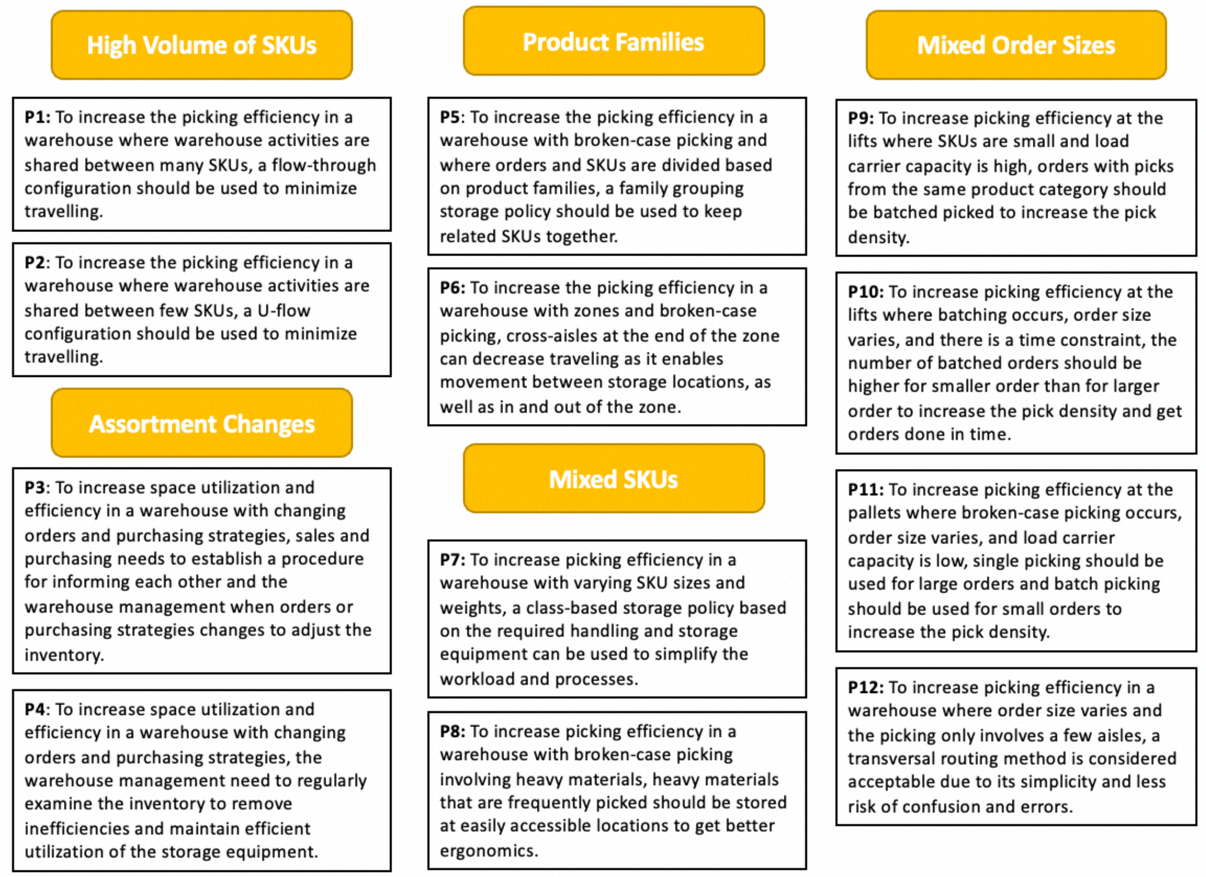


Figure 59. Summary of the developed propositions based on the contextual factors.

5.3 Practical Implications for Tetra Pak

5.3.1 Increased Collaboration & Maintenance to Improve Space Utilization

One of the bottlenecks that was identified was the space utilization at a maximum level. Proposition three and four implies suggestions on how to remove the wastes that contributes to the maximum space utilization. Table 56 shows a summary of the practical implications of these propositions.

Table 56. The practical implications of proposition 3 and 4.

Propositions	Practical Implications
P3: *To increase space utilization and efficiency in a warehouse with changing orders and purchasing strategies, sales and purchasing needs to establish a procedure for informing each other and the warehouse management when orders or purchasing strategies changes to adjust the inventory.*	Increased collaboration between the different departments to stop from waste entering the inventory. With better information flow faster and proactive decisions can be made. However, it is important to know how to deal with different scenarios. This requires sense of urgency and responsibility.
P4: *To increase space utilization and efficiency in a warehouse with changing orders and purchasing strategies, the warehouse management need to regularly examine the inventory to remove inefficiencies and maintain efficient utilization of the storage equipment.*	Increased maintenance of the inventory to remove existing waste in the inventory. This also requires that there is an agreement on how to deal with different scenarios and there is sense of urgency and responsibility. For example, how to deal with dead stock, which requires management to take decisions.

Proposition 3 means that there need to be an increased collaboration between sales, purchasing, and the warehouse because their work strongly influences each other. Thus, communication between the departments is needed to establish a better information flow, which enables faster decisions that can stop waste in the inventory before they reach the warehouse. However, this requires that they establish a procedure for knowing how to deal with different scenarios and who is responsible. Otherwise, they can just ignore the problem as no one is responsible and let it become a waste in the inventory. Thus, it is important to create sense of urgency in the situation to hinder waste from entering the system.

Furthermore, proposition 4 implies that it is not enough to only reduce waste in a proactive manner, but there needs to be a procedure for handling waste that is already in the system as well. This requires increased maintenance from the warehouse to regularly inspect the inventory, find waste and remove them, which is necessary due to the shifting assortment. Similarly, it is important that there is a sense of urgency by having responsibility. For example, materials are associated with a cost and management can avoid taking decisions about dead stock because of their value. Thus, no one wants to be responsible, and it just ends up as waste in the system. Figure 60 illustrates how an increased level of collaboration and maintenance will move Tetra Pak from misconfiguration to reduced wastes because they have a high level of variations in assortment. Tetra Pak can also try to decrease the variations in assortment to reduce wastes, but that is harder as it is one of the contextual factors.

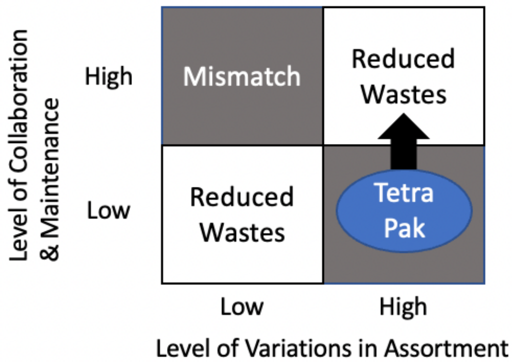


Figure 60. Tetra Pak needs to increase their level of collaboration and maintenance to reduce wastes.

The wastes that are expected to be reduced based on the recommendations are seen in Table 57. By having better communication and maintenance, SKUs will probably have less risk of being stored in the wrong types of bins. If the warehouse gets information from purchasing about changed strategies, the warehouse can change the bin data of the material. For example, if the amount of safety stock has decreased, this may require a smaller bin. Maintenance also increases the chance of finding materials that are not stored correctly. This is estimated to go from a medium severity level to low because there is still a risk that SKUs will be stored inefficiently due to full space utilization. Furthermore, increased collaboration and maintenance can also result in less bins that are dedicated to outdated materials and dead stock. This also involves the waste of having empty bins dedicated to outdated materials. Purchasing can communicate which materials that are not relevant anymore and warehouse can find what materials that have not been picked for a while and investigate their demand. Empty bins that are dedicated to outdated materials is estimated to be eliminated as the purchasing will update the warehouse about which materials that are not relevant anymore. Storing dead stock or outdated stock is estimated to be reduced to a medium level of severity because there will still be dead stock in the system as it takes time for management to take decision about the materials.

Table 57. Estimated impact on wastes due to increased collaboration and maintenance.

Identified Wastes	**Description**	**Change of Severity**	**Reason**
Over processing	Storing SKUs inefficiently	2 → 1	Warehouse can know in advance when purchasing strategies changes and adjust bin data. Maintenance increases the chance of finding SKUs that are inefficiently stored.
	Empty bins that are dedicated to outdated materials.	3 → 0	The warehouse will know what materials that are not relevant anymore through better communication and maintenance.
Inventory	Storing dead stock or outdated stock.	3 → 2	The warehouse will know what materials that are not relevant anymore through better communication and maintenance.

Another waste that was identified related to the space utilization, but a waste that will probably not be reduced through the solution above, is excessive amount of inventory, such as buffer stock or safety stock. Thus, Tetra Pak can consider doing a deeper analysis about that in the future. As this is more related to purchasing, this was found to be out of the scope for this study.

5.3.2 New Zone Configuration to Remove Wastes from the Lift & Pallet Processes

The processes at the lifts and pallets racks where also identified as potential bottlenecks because the capacity is sometimes not enough to meet the demand. The propositions in Table 58 and Table 59 were found to be related to the lift and pallet processes, and how a better zone configuration can look like. This involves new picking zones and their picking process, but also changes to materials that should be stored in the zones. The goal with a new zone configuration is that it will remove some of the wastes that contributes to the potential bottlenecks.

To begin with, the practical implication of propositions 1, 2, 5, 6, and 12 that are discussed in Table 58 are about highlighting configurational elements that are already aligned with the contextual factors. Thus, these elements should be kept when designing a new zone configuration since they contribute to the picking performance. Furthermore, these propositions should also be considered if there will be changes to the current warehouse or if a new warehouse will be designed in the future.

Table 58. The practical implications of proposition 1,2, 5, 6 and 12.

Propositions	Practical Implications
P1: *To increase the picking efficiency in a warehouse where warehouse activities are shared between many SKUs, a flow-through configuration should be used to minimize travelling.*	Have SKUs with more activity in the south warehouse where there is a flow-through configuration.
P2: *To increase the picking efficiency in a warehouse where warehouse activities are shared between few SKUs, a U-flow configuration should be used to minimize travelling.*	Have SKUs with less activity in the north warehouse where there is a U-flow configuration.
P5: *To increase the picking efficiency in a warehouse with broken-case picking and where orders and SKUs are divided based on product families, a family grouping storage policy should be used to keep related SKUs together.*	Have SKUs that are picked by pieces in zones based on HP, HT and BPU.
P6: *To increase the picking efficiency in a warehouse with zones and broken-case picking, cross-aisles at the end of the zone can decrease traveling as it enables movement between storage locations, as well as in and out of the zone.*	Have cross-aisles at the end of the zone to enable movement between storage locations, and in and out of the zone.
P12: *To increase picking efficiency in a warehouse where order size varies and the picking only involves a few aisles, a transversal routing method is considered acceptable due to its simplicity and less risk of confusion and errors.*	Continue to use a transversal routing method.

Instead, Table 59 includes the practical implications of proposition 7 and 8 that will affect the new zone configuration of the warehouse. Especially, proposition 7 involves many practical implications for the warehouse and how new zones can be configured to potentially reduce wastes.

Table 59. The practical implications of proposition 7 and 8.

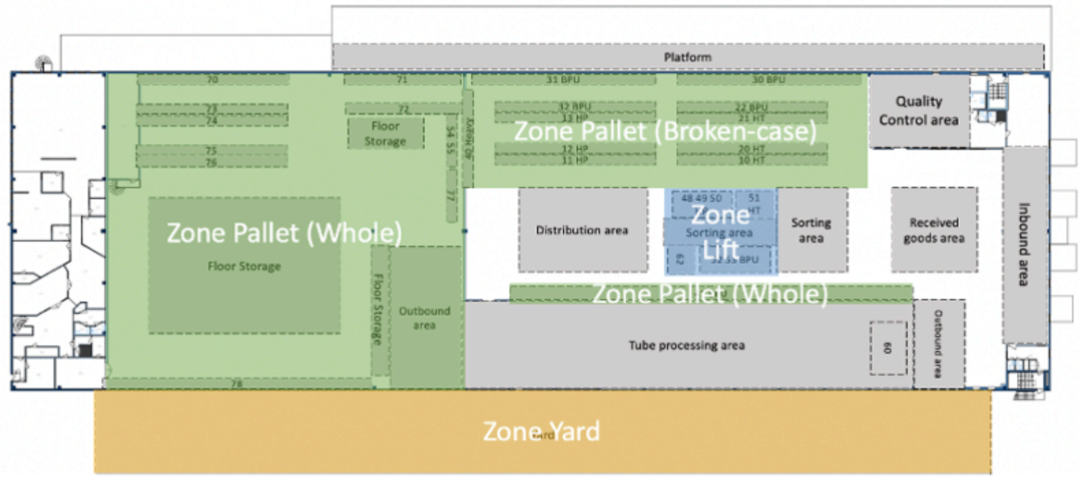
Propositions	Practical Implications
P7: *To increase picking efficiency in a warehouse with varying SKU sizes and weights, a class-based storage policy based on the required handling and storage equipment can be used to simplify the workload and processes.*	Today the picking zones are only based on storage equipment, but should also consider the handling equipment. Thus, there should be one zone for order-picking trucks, one zone for reach truck and counterbalanced forklift, and one zone for lifts. To use the zones efficiently, the picking group should be responsible for all the picks in the warehouse and all pallet pickers should be responsible for put-away. Furthermore, the categorization H01 and M01 should be changed to only one category that indicates that materials have lower weight than 15kg to avoid placing materials in wrong locations. There should also be a shared storage policy within zones to use space efficiently. Lastly, current lifts should be maximized with shelves, but another lift can also be relevant to have small SKUs in the lift zone.
P8: *To increase picking efficiency in a warehouse with broken-case picking involving heavy materials, heavy materials that are frequently picked should be stored at easily accessible locations to get better ergonomics.*	Frequently picked heavy materials above 15kg should be stored in the heavy lift. Frequently picked medium heavy materials below 15kg should be stored in the pull-out units.

The current state shows that SKUs are divided into many different areas such as north and south warehouse, lifts, pallet racks for broken-case picking and whole pallets, floor storage, yard.

There are also many different storage types that divides the material. Yet, there is only three picking zones today, which is the lift zone, pallet zone, and yard zone, and they are mostly based on only the storage equipment. To simplify the workload and processes, a class-based storage policy based on both the required handling and storage equipment should be utilized. Figure 61 illustrates the old and the new zone configuration.

Old Zone Configuration

	Zone Pallet	Zone Lift	Zone Yard
SKU Size	Small, Medium, Large	Small	Large
SKU Weight	Low, Medium, Heavy	Low	Heavy
Storage Method	Floor (inside), Pallet	Lift	Floor (outside)
Picking Method	Broken-Case, Whole Pallets	Broken-Case	Whole Pallets
Handling Equipment	Order-Picking Truck, Reach Truck, Counter-balanced forklift	Lift	Counter-balanced forklift



New Zone Configuration

	Zone Whole Pallets	Zone Lift	Zone Broken-Case Pallet
SKU Size	Medium, Large	Small, Medium	Small, Medium
SKU Weight	Heavy	Low, Medium, Heavy	Low, Medium
Storage Method	Floor, Pallet	Lift	Pallet
Picking Method	Whole Pallets	Broken-Case	Broken-Case Picking
Handling Equipment	Reach Truck, Counter-balanced forklift	Lift	Order-Picking Truck, (Reach truck)

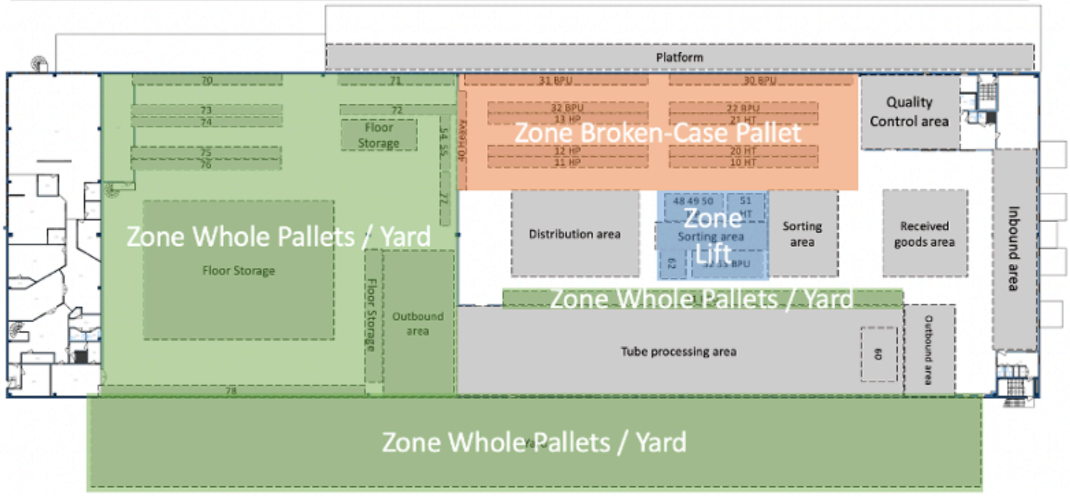


Figure 61. The old and new zone configuration.

Thus, having the lifts as one zone is still suitable. However, the pallet picking involves using both order-picking truck and reach truck, sometimes also the counterbalanced truck. The yard mostly involves a counterbalanced truck. Therefore, a more suitable solution would be to have three zones, one with order-picking truck, one with reach truck, and one with the counterbalanced truck. Nevertheless, the north warehouse and yard only have a few picks per day, shown in Table 43, and the service level in Table 47 and Table 48, along with the current VSM data in Figure 44 show that the yard is less of a potential bottleneck than the lift and pallet process. Also, both the yard and the north warehouse have similar storage equipment and deals with similar SKUs, that is larger and heavier SKUs where one item at a time is picked. Thus, it is suitable to make one zone where both the reach truck and counterbalanced forklift is used, especially since there is a counterbalanced forklift in the north warehouse that can be used in the yard. Separating these areas increases the risk of having too little workload on each zone. This will create a larger zone with more responsibility and sense of urgency, as well as minimizing the switching of order-picking truck and reach truck. Furthermore, this also means that the yard becomes part of the picking team, and that the zone will be included in the job rotation. This results in more varying workload for the employees, as well as making sure that everyone knows the different zones and can cover for each other if someone cannot work.

This suggested zone configuration is possible to utilize today because of the different storage types and storage sections. Materials that require a reach truck is mostly in the north warehouse, in pallet rack 41, or pallet locations on the highest level of the rack. There are also materials that are defined as L01, meaning that they weigh over 15kg and are mostly stored in pallets in the south warehouse except pallet rack 41, and they must be taken down with the reach truck. However, the pallet racks are divided into sections, which means that all L01 positions are placed in the same rack section. Thus, it is easy to divide where each type of truck is needed and used. For this to work even more efficiently though, the materials stored at the highest level of the pallet rack should be the buffer stock again that was moved to another warehouse. This is because buffer stock is then close to their replenishment locations and the reach truck is not needed for broken-case picking, only to pick down a whole pallet. Instead, dead stock can be placed in the other warehouse while waiting on a decision from management. This minimizes traveling between the warehouses as the dead stock has no demand. Furthermore, proposition 8 also implies that L01 materials should be stored in a heavy lift, which minimizes the use of a reach truck at the broken-case pallet racks.

Proposition 7 also involves having all the pallet pickers responsible for put-away like the lift process. By doing that there will also be less switching between trucks and create more sense of urgency in the group as responsibility is shared. Furthermore, the recommendation also involves having the picking team responsible of the pick-lines of service and delivery too, which often are just a few pick-lines. This is to avoid congestion in the picking zones by only letting the picking team do the picking. Figure 62 illustrates how the old process related to the zones will change to become the new picking process.

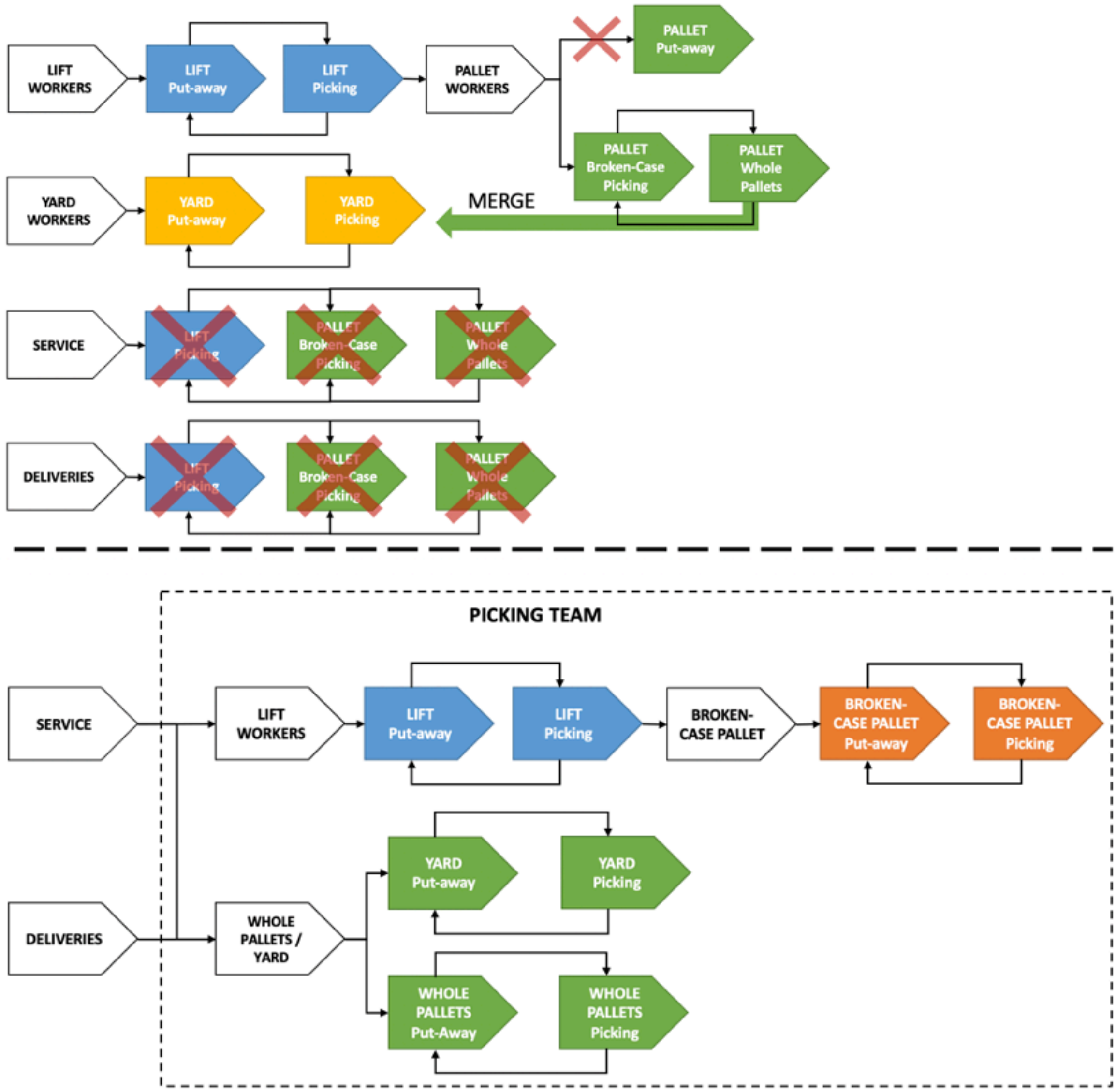


Figure 62. The old and new picking process related to the zones.

Figure 63 also show how the new zones affect the material flow by illustrating it in a future VSM. As seen in the figure, the material flow and the processes are quite similar as before. The only change is that the flow that represents whole pallets will move from going through step 6 and 13, and instead go through 7 and 14. This new material flow divides up the broken-case materials to the lifts and south warehouse, while having whole pallets to the north warehouse and yards. Furthermore, to make the material flow even more efficient, the inventory steps 3, 4, 15, and 16 should be removed according to lean principles as they are considered as waste. A solution here, which is aligned with the new configuration, is to deliver whole pallets directly to the production. As whole pallets need to be taken with the tow truck that only can take two pallets at a time, it might save time to just leave the materials directly. This is something Tetra Pak can investigate further in the future.

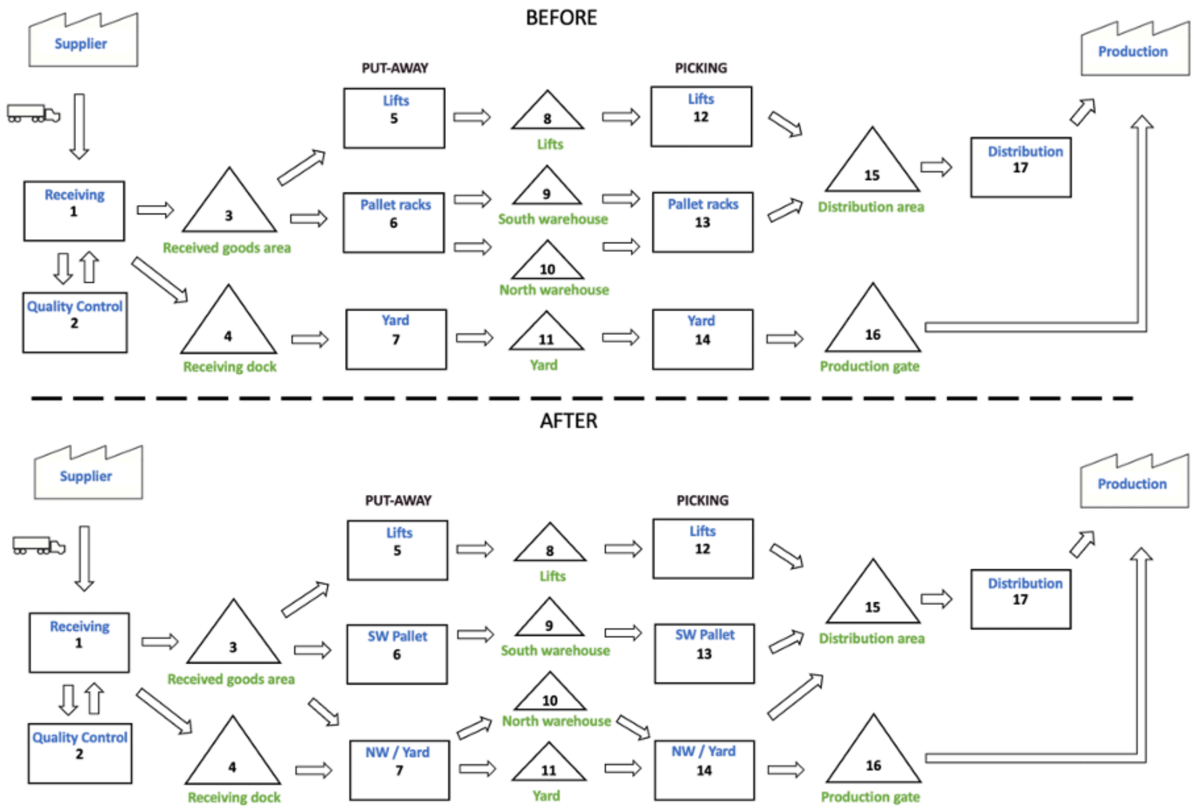


Figure 63. Future VSM map that visualise the new material flow due to the new zones.

Proposition 7 also implies that the categorization of M01 and H01 should not be used, which they mostly have on materials that are stored in pallets in the south warehouse. Instead, it is better to only define materials in two ways, that is if they weigh more or less than 15kg. This is because when the system finds storage locations it will first search within the storage type and the storage section, for example 120 H01 and if there are no locations it will search within the storage type and for all storage sections. Thus, the worst case is if it chooses a L01 location. L01 requires a reach truck, while the other two storage sections require order-picking truck. As a results, it will be hard to determine where to use which type of truck. However, it is possible to keep the definitions, if the ERP system can search for 120 H01 and then 120 M01, and vice versa, and lastly it searches for 120 L01 or that it must be handled manually then. It will also be necessary to regularly examine the pick frequency and change materials accordingly, otherwise there is no point with the definitions. This type of volume-based storage policy can be suitable if there is time for maintaining it and when some SKUs are more popular than others. However, as mentioned in the frame of reference by Petersen and Aase (2004), a simple class-based storage policy can almost achieve the same benefits as a much more information intensive volume-based storage policy. According to Bartholdi and Hackman (2019) a class-based storage policy can bring the benefits from both a dedicated and shared storage policy as SKUs that are picked together are close, while having a shared storage policy that contributes with better space utilization.

This also suggests that a shared storage policy should be used within the class-based storage policy as space utilization is important for the warehouse. This affects the HP lifts as it has a dedicated storage policy, which has resulted in congestion because most picks are from the lifts 48 and 49. There is no point of having a dedicated storage policy for the lifts as better inventory accessibility is not needed because shelves are retrieved. Instead, space efficiency is more important as the warehouse need more storage locations, which is a benefit of a shared storage policy because space is recycled faster according to Bartholdi and Hackman (2019). Thus, space utilization will increase because empty bins can be given to other materials. Also, by having a shared storage policy, material will be placed more randomly and probably even out the activity in the HP lifts. In addition, this will minimize the risk of having bins dedicated to material that are not purchased anymore. Other ways to solve the congestion of the lifts is to have lifts with twin function or to change frequently picked materials with infrequently picked materials for the different lifts to even out the activities.

The last practical implication connected to proposition 7 is about maximizing shelves on the existing lifts 48 and 49, which is possible shown in Figure 23 because of the free space for additional shelves. If there are still items that can be stored in the lifts after getting more shelves, it can be worth considering getting one more lift. The weight distribution of the stored goods in Table 31 shows that there are many lightweight materials stored in pallets. There are 541 materials in pallets in the south warehouse that weigh between 0.01 – 0.99 kg and 877 that weigh between 1 – 4.99 kg. This suggests that there are items on pallets that can be stored in lifts. Today there are 4917 materials stored in the lifts that have a weight between 0.01 – 4.99 kg. As there are six lifts today, this means 820 materials per lift. If the heavy lift is used in the same way as the other lifts, it can be enough with just getting additional shelves. However, if the heavy lift is going to store pallets instead of bins as it is today, another lift can be suitable. The detailed planning of this requires further investigation, as well as what items that should be stored in the new shelves or lift, and where a new lift should be installed.

The practical implication of proposition 8 is about putting heavy materials that are picked by pieces on storage locations that supports heavy picking. In the case company warehouse this means the heavy lift and the pull-out units. This also means that it is suitable for them to have a dedicated storage policy. The lift means better ergonomics than the pull-out units because pull-out units require the worker to bend down to grab the item. However, they are still better ergonomically than order-picking trucks as it avoids twisting and reaching. Lift 62 also has heavy picking aid. Thus, items that weigh more than 15kg can be stored in the heavy lifts. This also means avoiding taking down a pallet and then place it back up again. However, this might not be possible as the lift have a maximum capacity of 500kg per pallet. Yet, it is suitable to store heavier items in the lift because of its ergonomic benefits. Appendix F suggest materials that could be suitable to have in the heavy lift. Furthermore, items that are heavy but have a weight below 15kg can be placed in the pull-out units because the truck is not required at the floor level. This also skips double-handling in terms of consolidation because heavy items are not moved from a pallet to the load carrier since the load carrier can be used directly. Appendix E suggests materials that are more suitable to have in the pull-out units. Figure 64 gives an overview of where different materials should be stored based on the previous discussion.

Whole Pallets			
	Pallets	Floor (NW)	Yard
SKU Size	Medium, Large	Large	Large
SKU Weight	Heavy (>15kg)	Heavy (>15kg)	Heavy (>15kg)
Other	-	Sensitive	Not sensitive

Zone Lift		
	Other lifts	Heavy lift
SKU Size	Small	Small, Medium
SKU Weight	Low (0-5kg)	Heavy (>15kg)

Broken-Case Pallet			
	Other Racks	Pull-out units	Highest Level
SKU Size	Medium	Small, Medium	-
SKU Weight	Low, Medium (0-10kg)	Medium (10-15kg)	-
Other	-	Popular SKUs	Buffer

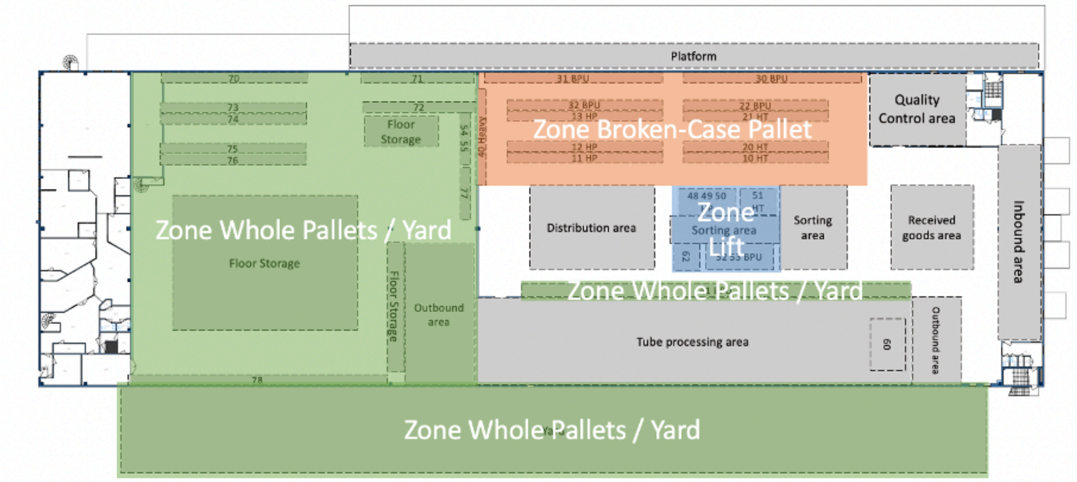


Figure 64. Overview of where different types of SKUs should be stored.

The estimated impact that the practical implications discussed above will have on the wastes are summarized in Table 60. As the new zone configuration will result in less switching, sharing, and coordinating with trucks, the related wastes will potentially be reduced. This can possibly decrease the risk of pick errors, as there are less interruptions in the work. Also, as the heavy lift previously stored small and light items, and the lift was slower than the other ones, there will probably be reduced waiting time for shelves if the items are moved to another lift. In addition, if heavy materials are placed in the heavy lift, instead of the pallet racks, the waiting time will reduce as there will be less materials per shelf. This solution also means that there will be less pallets that are picked down and placed back again. It also contributes to better ergonomics for the pickers, together with putting heavy items in the pull-out units. Furthermore, a shared storage policy can possibly even out the congestion of the lift 48 and 49, and therefore reduce the waiting time. Also, by removing the categorization H01 and M01 there is less risk that these occupy the L01 storage section, which means that SKUs are placed at more optimal locations and less coordination between trucks is needed. Two wastes were estimated as having no change. These wastes can be further analysed by the case company to improve the picking performance even more.

Table 60. Estimated impact on wastes due to the new zone configuration.

Identified Wastes	**Description**	**Change of Severity**	**Reason**
Waiting	Waiting for trucks when the required one is not available.	3 → 0	New pick zones and processes with less sharing between trucks.
	Wait for shelves as SKUs are not stored at their optimal locations.	3 → 2	Utilize the heavy lift more efficiently and use a shared storage policy for the HP lifts to avoid congestion.
Transportation	Additional transportation when SKUs are not stored at their optimal locations.	3 → 2	Have heavy pallets in the heavy lift. Remove H01 and M01 categorization to utilize the reach truck better. Change location of the buffer stock. Have small SKUs in the lifts.
	Switching between trucks.	3 → 1	New pick zones and processes with less switching between trucks.
Over processing	Double-handling	2 → 1	Have heavy pallets in the heavy lift to avoid double-handling when broken-case picking.
	Coordinating trucks between workers.	3 → 0	New pick zones and processes with less switching between trucks.
Motion	Picking heavy items when using the order-picking truck.	3 → 1	Utilize the pull-out units and heavy lift for heavier items.
	Searching for trucks if they are not available.	3 → 0	New pick zones and processes with less switching between trucks.
Defects	Pick errors (pallet)	3 → 2	Less interruptions in the work process as there are less need for coordinating trucks.

Waiting for trucks is estimated to be entirely removed as forklifts will be less shared and there are less people that need the forklifts if the picking team takes all the pick-lines. Thus, all pickers should have the correct types of forklifts available. This also means that coordinating and searching for trucks will also be removed. Waiting for shelves will go from a high level of severity to a medium level of severity because the lifts will be utilized more efficiently, but there will still be longer waiting time for the lifts without twin function as it is hard to solve completely. Transportation will also be reduced from a high level to a medium level because there will be less switching of trucks during the broken-case picking as heavy materials are stored more in better locations. If dead stock will be moved to the other warehouse where the buffer stock is now, travelling will be reduced as it is not necessary to travel to the other warehouse. However, there will probably still be SKUs that are stored in locations that are not optimal when there are no free storage locations left.

Furthermore, switching between trucks will also be reduced to a low severity level because of the new zones and processes, but there will still be switching between trucks for the yard and north warehouse zone. Yet, less than before as one can be responsible for the reach truck and one can be responsible for the counter-balanced forklift. Double-handling will be reduced from a medium level to a low level because the heavy lift will store the pallets that required double-handling during broken-case picking. However, since all pallets cannot be placed in the lift due to its capacity constraint, the waste will not be eliminated. In addition, there will be better ergonomics if heavier items are stored in the pull-out units and heavy lift, but it is hard to remove this waste entirely. Thus, the severity level goes from high to low. The severity level of pick errors will only change from a high level to a medium level because there are still other reasons for pick errors to occur, such as lack of confirmation at the lifts.

5.3.3 Batch Picking to Improve Lift & Pallet Picking Performance

It was also found that the propositions, summarized in Table 61, can be used to further improve the picking performance related to the lift and pallet process. By batching orders with pick-lines from the same storage types, it is possible to increase the pick density and reduce travelling. As it is possible to have several load carriers at the lifts, sorting can happen directly. In addition, picks from the pallet racks need to be consolidated with the lift picks on the load carriers. As sorting occurs today, batching will probably not require that much additional time. Thus, batching during lift and pallet picking will potentially increase picking efficiency.

Table 61. The practical implications of proposition 9, 10, and 11.

Propositions	**Practical Implications**
P9: *To increase picking efficiency at the lifts where SKUs are small and load carrier capacity is high, orders with picks from the same product category should be batched picked to increase the pick density.*	Batching should be done at the lifts to increase the picking efficiency. However, this might increase the risk of pick errors. Finger scanners can be considered for confirming picks.
P10: *To increase picking efficiency at the lifts where batching occurs, order size varies, and there is a time constraint, the number of batched orders should be higher for smaller order than for larger order to increase the pick density and get orders done in time.*	Larger order at the lift should only be batched two and two, such as large HP-orders. Smaller orders with only a few pick-lines can have more orders being batched. Sorting is done directly by placing items on the correct load carrier.
P11: *To increase picking efficiency at the pallets where broken-case picking occurs, order size varies, and load carrier capacity is low, single picking should be used for large orders and batch picking should be used for small orders to increase the pick density.*	Small orders with only a few pick-lines should be batched together at the pallet picking. Sorting is done when consolidating material with the lift picks on the correct load carrier. Information system might not currently support batching.

Figure 65 illustrates when Tetra Pak should use single picking and batch picking based on load carrier capacity and order size.

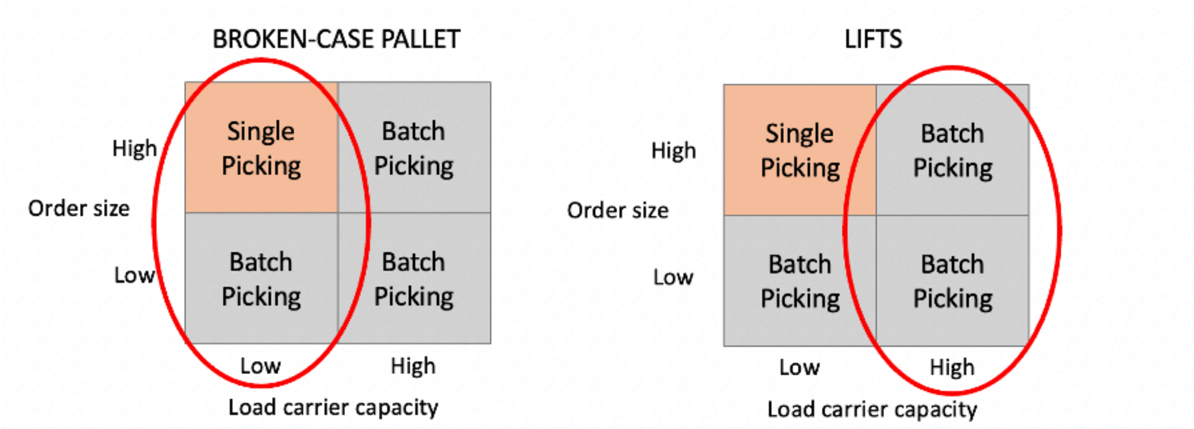


Figure 65. When Tetra Pak should utilize single picking and batch picking.

As it is possible to have more load carriers by the lifts, batch picking is found to be useful no matter the order size. For broken-case pallet picking, it is not possible to have several load carriers on the truck, only a pallet. Thus, load carrier capacity is low, which mean that single picking should be used for large orders and batch picking for smaller orders. Also, batch picking should only be utilized for orders of the same product category for picking to occur within the same area and reduce travelling.

Batching is possible with the system in the lifts today, but it might not be supported by the information system in the forklifts. Therefore, further investigation can be necessary. Nevertheless, this solution will increase the risk of pick errors. The HP lifts has by far the most pick errors today. One solution to reduce the risk of pick errors at the lifts is to have finger scanners as a mean to confirm that the correct item has been picked, which is not done today. However, batching can also require that items are confirmed when sorting as well. Furthermore, proposition 10 suggests that less orders should be batched for large orders as their pick-density is already large, and that more orders should be batched for smaller orders as it only contains a few pick-lines and increases pick-density. However, it is important to keep in mind that this depends on the worker and its experience. Batching is suitable for more experienced workers.

The estimated impact that batch picking will have on the wastes related to the lift and pallet process is seen in Table 62. Since batch picking has been estimated to have an impact on some of the same wastes as the new zone configuration, the severity levels used for those includes the estimated improvements based on the new zone configuration. As the pick density will increase due to batching, SKUs have more suitable locations and there will be less waiting for shelves and less transportation. Furthermore, there will be less waiting time for lift 48 and 49 as more SKUs on the same shelf can be picked at once. The wastes will not be eliminated as SKUs are still stored at locations that are not optimal, but with batching the transportation and waiting will be reduced to some extent. In addition, the risk of pick errors can increase as there are more orders to keep track off and batching can involve sorting errors. Finger scanners at the lifts can be used to reduce the pick errors at the lifts, but there might need to be additional confirmation when sorting as well to avoid errors. Lastly, batching can also contribute to less switching and waiting for trucks as more picks can be done from the same truck during the same route. However, this waste was found to be eliminated due to the new zone configuration.

Table 62. Estimated impact on wastes due to batching.

Identified Wastes	**Description**	**Change of Severity**	**Reason**
Transportation	Additional transportation when SKUs are not stored at their optimal locations.	2 → 1	Batching increases pick density.
Waiting	Wait for shelves as SKUs are not stored at their optimal locations.	2 → 1	Batching increases pick density.
Defects	Pick errors (lift)	3 → 2	Batch picking increase the risk of pick errors, but finger scanners at the lifts can decrease it by better confirmation. Confirmation during sorting can also avoid pick errors.

5.3.4 Summary of the Waste Reduction

Based on the practical implications and the estimated impact that they will have on the wastes connected to the bottlenecks, a new total score that gives an overview of all the identified wastes and their new impact have been calculated. Figure 66 show how the impact of the wastes looked before and how it is estimated to look after the recommendations. This shows that the practical implications of the propositions are expected to significantly reduce several types of wastes connected to the different bottlenecks. This means that the solutions based on alignment between contextual factors and warehouse configuration, that were related to the bottlenecks, should reduce waste levels of the bottleneck. Thus, increasing warehouse performance.

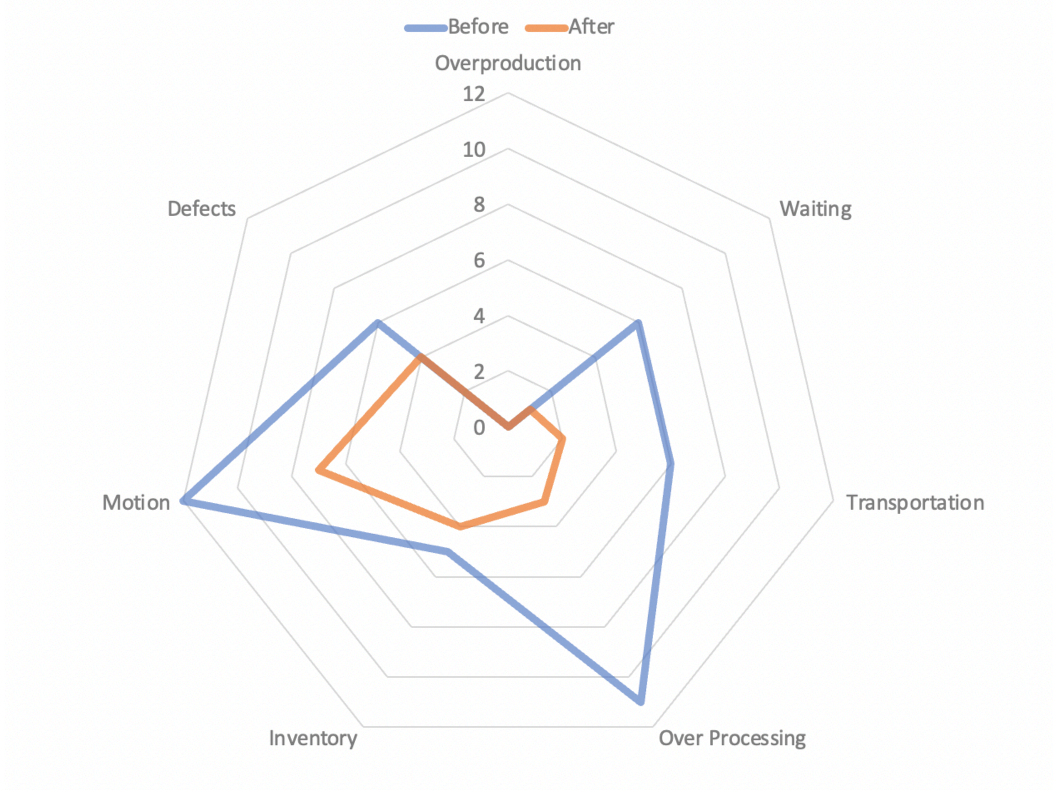


Figure 66. Impact of recommended solutions on the identified wastes of the bottlenecks.

6. CONCLUSION

This last chapter aims to summarize the conclusions of the study. The chapter begins with linking back to the purpose and research objectives of the thesis and how these have been addressed. The practical and theoretical contributions will be presented in the next subchapter. The chapter will also present the limitations connected to the study to highlight its validity and reliability, and end with a discussion about future research related to the findings of this study.

6.1 Fulfilling the Purpose by Addressing the Research Objectives

The purpose of this thesis was to develop a solution for how to increase warehouse picking efficiency by identifying and solving material-flow bottlenecks and wastes related to the picking process. A design science approach was used to fulfil the purpose because it aims to design a solution and contribute to both theory and practice, which is the overall aim of this thesis project. Two research objectives were formulated to help fulfil the purpose of the thesis. The first objective was:

RO1: *Develop an artifact based on contextual factors and lean practices to improve warehouse picking performance.*

The developed solution was an artifact that works like a framework and was based on prior theories. More specifically, it was based on lean practices such as value stream mapping, bottleneck management, and waste analysis. It was also based on contextual factors, which mean that the configurational elements in terms of warehouse operations, design, and equipment should match the context. Both lean practices and aligning configuration with context aims to improve efficiency, meaning they are suitable for the purpose of the artifact. The created artifact based on these theories provides guidance for what data that should be collected and how to analyse the data. The artifact was evaluated, which is connected to the second research objective:

RO2: *Test and evaluate the artifact by applying it to the Tetra Pak production warehouse.*

To evaluate the artifact's ability to identify and solve material-flow bottlenecks and wastes, it was tested by conducting a case study at the Tetra Pak production warehouse. A single case study provides great depth, which was suitable when testing the artifact in a real-life context. In addition, the study of the artifact included asking "how" and "why" questions such as how it performs and why it is effective.

The artifact was found useful when applied to the case company. To begin with, it supported the data collection in terms of indicating what was needed to be collected. The different data collection methods of a case study were used to gather the data, such as interviews, observations, documents, and system data. Furthermore, the artifact supported the analysis of the data because of the analytical tools included in the artifact. This means that bottlenecks and its wastes were identified in the picking process with the help of the VSM that was based on the current state of the warehouse. Three bottlenecks were found at the case company which were the space utilization, pallet picking process, and the lift put-away and picking process. After areas of improvement had been located, it was possible to formulate solutions to manage the wastes of the bottlenecks. The contextual factors were helpful here because it provided understanding of what configurations that were suitable in a specific context. This also means how to reduce wastes because of misalignments and increase picking efficiency.

As a result of utilizing the two parts of the artifact, meaning the current state and analysis, general propositions were formulated. The 12 propositions were based on prior theory on warehousing, the empirical findings of the current state, the wastes, and the contextual factors.

These propositions could be applied to the case company to give them recommendations on how to reduce waste in the picking process and improve their picking performance. The practical implications were that they should increase collaboration and maintenance to improve space utilization, use a new zone configuration to remove wastes at the lift and pallet processes, and use batch picking to increase the performance of the lift and pallet picking. As these recommendations are based on better alignment between the contextual factors and the configurational elements, wastes connected to the potential bottlenecks will likely be reduced. Thus, increasing picking performance. This shows that the artifact and the propositions that it developed were helpful for solving material-flow bottlenecks and wastes, and for increasing the picking performance.

As the artifact was based on well-grounded and comprehensive theories, and was designed to have a systematic approach, it was found to be helpful and flexible when collecting and analysing the data. An extensive amount of data needed to be collected to understand the current situation of the warehouse and the analytical tools could be applied at any area that was found to be of interest. The study also showed how the lean practices and contextual factors could be used and complement each other. The lean practices were used to get a deeper understanding about the problem, while the contextual factors provided guidance for developing solutions. Wastes were also useful when understanding how contextual factors influence configuration because they could be used as indicators for determining where there are misalignments. This suggested how a more suitable solution could look like. Furthermore, the artifact was altered during the case study, as the study showed that some prior theories were missing in the beginning. This means that the artifact was adapted based on the flaws that became evident during the study to become more efficient. In the end, the artifact helped to develop recommendations on how to increase the picking efficiency by identifying and solving bottlenecks and wastes, which was done in a systematic manner.

6.2 Practical & Theoretical Contributions

This study contributes to both practice and theory. The artifact can be used by warehouses as a framework for increasing their performances. As the artifact was applied to the production warehouse of Tetra Pak it contributed to practice by giving them recommendations on how to solve their bottlenecks and wastes to increase their number of picks per day. This also means that a new theoretical framework has been developed as it combines theories based on lean practices and the contextual factors and has explored how they can work together. Furthermore, 12 general propositions were formulated that can be used in other cases. It also contributes to research because it shows that lean practices in terms of value stream mapping, bottleneck management, and waste analysis can be applied to a warehousing context to identify challenges and increase the picking performance. Thus, it contributes to already existing research on lean in a warehousing context, but an area that still is scarce. Furthermore, the study continues to build on prior theory about contextual factors as it highlights the importance of understanding the context and that solutions should be made based on them. It is an effective tool for determining suitable organizational decisions to increases performance. Lastly, this thesis contributes with a study that uses a design science approach in operational management.

6.3 Limitations

To begin with this thesis was a single-case study that provided great depth. However, a multiple-case study would increase the generalizability of the study, which would show that that the artifact can be applied to other contexts than the one case company. The formulated propositions would also have more generalizability as they would be based on several contexts. It is not certain that the propositions are suitable in other contexts as they are based on only one case. Also, this artifact focused on the picking performance and a more general artifact would be if it can be applied to the entire warehouse, meaning all its processes and increase their performance. In addition, the artifact was adjusted during the study to fill the missing gaps and therefore it can require a new study to test the value of the final version of the artifact. On the other side, the artifact is based on prior theories such as lean practices and contextual factors that are of a general kind. Thus, this can increase the artifact's generalizability to other parts of the warehouse and to other warehouses. Also, the performance of the artifact can be regarded as more acceptable as it is based on prior well-grounded theory for increasing performance.

The thesis was also limited to 20 weeks, which affected the level of details. A longer study could mean that the recommendations were implemented, and a study of its effects could have been made. This would have tested and evaluated the performance of the artifact even more in-depth. However, the recommendations were discussed with key people at Tetra Pak to avoid inappropriate suggestions. Furthermore, the severity of the wastes and their changes were only approximations based on reasoning, and they could have been estimated better by collecting data on probability and impact of the wastes. A deeper analysis of how the recommendations would have impacted the severity levels could also have been made. A longer study could also have involved more propositions based on further analysis, as well as in-depth recommendations with more details such as cost-analysis and implementation plan. It could also involve more areas of the warehouse that also affects picking. For example, the exact number of pick-lines involved for delivery and service, and how the change of the workload would affect the picking group.

Lastly, there was only one author of this thesis. However, since it was a design science study, it means that the study involved collaboration with the practical context. The work was mainly discussed with the supervisor at Tetra Pak during the entire study but also other key people at Tetra Pak, which is reflected in the conducted interviews. Furthermore, the study was discussed with the supervisor and opponents at the university during the 20 weeks. The opponents also did their thesis project at Tetra Pak Processing Equipment and therefore they could contribute with valuable insights about the practical context as well.

6.4 Future Research

Future research can involve studying the generalizability of the artifact by applying it to other warehouses to see how it performs, as well as other areas of the warehouse. This both includes other production warehouse and warehouses with other purposes, such as a distribution warehouse. This can show if the artifact works when it works or what additional adjustments it needs to work and become more general. Furthermore, studying the effects of the recommendations that were given based on the artifact can clearly show the performance of the artifact. This study can also be seen as a smaller study that is part of a larger design science study, as it develops design principles. By doing a multiple-case study and understanding other warehouses bottlenecks, wastes, and contextual factors, it is possible to formulate more general design propositions. This can be used to develop a new framework for determining how to solve different bottlenecks and wastes in different contexts.

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Appendix A: Interview guide

Picking

Can you explain the picking processes? In the yard and in the warehouse

What equipment are used?

How much time is spent on picking each day?

How much time does it take to pick one order/SKU?

What order picking method is used? (Single, batching, zone, batch zone, wave picking)

What routing method is used?

How many people are involved in this activity?

Are there any unnecessary tasks or errors during the process?

Put-away & Storage

Can you explain the put-away and storage processes? In the yard and in the warehouse

How many people are involved in this activity?

Are there issues with put-away and storage that affect the picking process?

How does space utilization usually look like?

How much time is spent on put-away and storage each day?

How much time does it take to put-away one order/SKU?

How are suitable storage locations located?

Storage policies (Product family, shared/dedicated, fast-picking area)

Packing & Shipping

Can you explain the packing and shipping processes? In the yard and in the warehouse

Are there issues with distribution that affect the picking process?

How many people are involved in this activity?

How much time does it take to distribute one order?

Are there any unnecessary tasks or errors during the process?

Contextual Factors

What is the purpose of the warehouse?

Who are the customers? Who are the suppliers?

When does an order have to be finished? (Takt time)

Are there any special requirements needed in the warehouse? For example, any SKU that needs special handling?

Any seasonality or other demand characteristics?

Warehouse layout and equipment

Layout & Storage Equipment

What area does the warehouse have?

How does the current warehouse look like? Placement of docks?

What was the reasoning behind the layout?

Are there any constraints with this layout?

How many storage locations do you have?

What different storage types are there?

What different storage equipment do you have?

What are the lane depths and stacking heights?

Handling Equipment

How many forklifts do you have? What sorts of forklifts do you have?

Are there any issues with the number of forklifts?

How do you use scanners? Issues?

Automation Solutions

Do you have automated storage solutions? How does it work?

What SKUs are stored there?

Are there any issues?

Information Systems

What information systems do you use? How are they connected/used?

Are there any issues with them?

Are you lacking any functions that you would like to have?

How do you measure performance of the warehouse?

Labour Management

How many workers are currently working with storage, picking and distribution? How are they divided?

How do they work in terms of shifts and hours?

Do you use any manpower planning strategies? (Flexible contracts, flexible planning, job rotation and workload balancing)

Appendix B: VSM example with data boxes

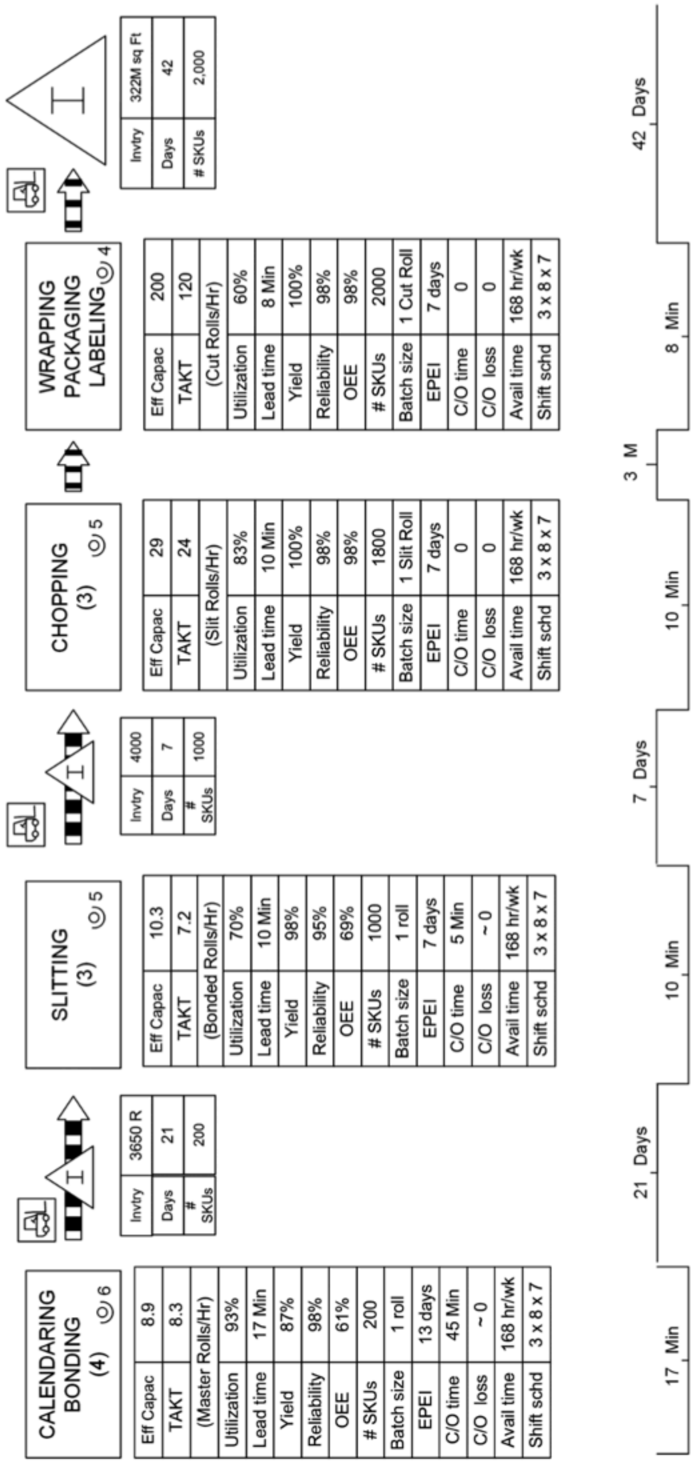

Figure B1. VSM example with data icons and timeline (King, 2019)

Appendix C: Heat map of the south and north warehouse

Figure C1. Heat map of the south (right) and north (left) warehouse

Appendix D: Popular SKUs

Table D1. Most picks between September 2021 and February 2022 for the lifts.

Nbr	Material number	Description	Storage type	Storage location	Nbr of picks	Percentage of total picks	Weight per piece (kg)
1	6-4723 1370 52	O-ring	120	48	339	0,60%	0,001
2	6-4722 8753 01	Back-up ring	120	49	339	0,60%	0,001
3	342991-0101	Hose clamp	120	48	267	0,47%	0,013
4	315102-0198	Washer	120	48,49	248	0,44%	0,028
5	90087-0015	Plug	120	48	246	0,43%	0,018
6	6-4350 8400 78	Connection	120	48	240	0,42%	0,073
7	6-4723 1370 16	O-ring	120	49,50	217	0,38%	0,003
8	6-4723 1370 08	O-ring	120	49	205	0,36%	0,002
9	311103-0460	Dowel pin	120	50	196	0,34%	0,022
10	6-4723 1370 15	O-ring	120	49	190	0,33%	0,003
11	6-881 17115	Seal Ring	120	49	187	0,33%	0,003
12	6-4722 0942 17	Valve sealing	120	48	182	0,32%	0,014
13	6-4723 1370 61	O-ring	120	48	181	0,32%	0,004
14	6-4722 1178 19	Support ring	120	50	178	0,31%	0,007
15	6-4723 1370 17	O-ring	120	50	177	0,31%	0,004
Total					**3392**	**5,96%**	

Table D2. Most pallet picks between September 2021 and February 2022 for the south warehouse.

Nbr	Material number	Description	Storage type	Storage location	Nbr of picks	Percentage of total picks	Weight per piece (kg)
1	6-4722 8752 01	Pressure gauge	440	11	179	0,76%	1,50
2	6-4723 1911 01	Hydraulic Unit	440	11	161	0,68%	7,38
3	70000153013	Housing	440	31	135	0,57%	0,60
4	6-9611 41 6470	Bracket	440	31	129	0,55%	0,28
5	90187-0069	Valve	440	31	127	0,54%	0,50
6	6-9613 13 9505	Valve body	440	11	125	0,53%	0,65
7	6-31319 0275 1	Pipe bend	440	11	124	0,53%	0,22
8	90520-7013	Seat valve	440	31	120	0,51%	1,40
9	6-31319 0219 1	Pipe bend	440	31	120	0,51%	0,12
10	6-4722 7446 02	Screw	440	22	118	0,50%	0,35
11	6-9612 93 9303	Clamp	440	31	117	0,50%	0,16

12	6-4722 1989 01	Bellows	440	11	115	0,49%	0,34
13	90519-8606	Pressure regulator	340	30	111	0,47%	0,83
14	6-9612 93 9304	Clamp	440	11	111	0,47%	0,19
15	6-9611 41 6301	Actuator	440	22	107	0,45%	2,65
Total					**1899**	**8,06%**	

Table D3. Most picks between September 2021 and February 2022 for the north warehouse.

Nbr	Material number	Description	Storage type	Storage location	Nbr of picks	Percentage of total picks	Weight per piece (kg)
1	6-4722 7368 02	Roller bearing	600	71,72,73,74,76,78	86	3,15%	58
2	6-1 648325 21	Shell	600	60	63	2,31%	29,58
3	6-32310 0163 4	PIPE	160	PIPE03	59	2,16%	0,45
4	6-32310 1690 1	Tube	160	PIPE05	57	2,09%	1,435
5	6-4722 7641 02	Crankcase	600	74,75	49	1,79%	1407
6	6-4723 1507 01	Gearbox	600	70,72,73,74,76,78	48	1,76%	265
7	6-1 648325 11	Shell	600	60	48	1,76%	17,62
8	6-4723 0883 80	Lower frame	600	70,71,72,73	47	1,72%	132
9	6-4722 7778 01	Motor beam rear	604	111N	47	1,72%	24,6
10	6-4722 7777 01	Motor beam front	604	111N	47	1,72%	64,65
11	6-4722 7775 80	Body complete	600,604	70,73,111N,LUN 03	47	1,72%	0
12	6-4722 7642 02	Crank shaft	160	VEVAXEL	46	1,68%	500
13	6-4722 7775 81	Body complete	600,604	70,71,72,73, 111N	45	1,65%	0
14	6-4722 7695 01	Pump block	160	PB-7695-01	42	1,54%	355
15	6-4723 3906 01	Outlet	160	78	33	1,21%	7,5
Total					**764**	**27,98%**	

Table D4. Most picks between September 2021 and February 2022 for the yard.

Nbr	Material number	Description	Storage type	Storage location	Nbr of picks	Percentage of total picks	Weight per piece (kg)
1	6-1535 528 146	Tube	601, 602	61, RÖR	56	4,69%	5,30
2	6-1535 528 280	Tube	602	RÖR	48	4,02%	0,30
3	3455073-0100	Frame	603	60	46	3,86%	1,00
4	6-1535 528 128	Tube	601	61	37	3,10%	3,13
5	6-1535 528 182	Tube	601	61	33	2,77%	5,29

6	6-1535 528 144	Tube	601	61	31	2,60%	6,36
7	6-31801 5932 2	Cable	603	60	31	2,60%	1,70
8	6-1 647619 06	Tube insert	602	KNIPPE	30	2,51%	10,00
9	6-1 647396 01	Tube insert	602	KNIPPE	28	2,35%	23,00
10	6-1 647619 01	Tube insert	602	KNIPPE	25	2,10%	37,00
11	6-1535 528 183	Tube	601	61	23	1,93%	6,36
12	6-1 647732 06	Tube insert	602	KNIPPE	23	1,93%	16,60
13	6-1 647396 02	Tube insert	602	KNIPPE	23	1,93%	23,00
14	6-1 647619 02	Tube insert	602	KNIPPE	22	1,84%	37,00
15	6-1 649009 01	Frame	603	60	22	1,84%	4,60
Total					**478**	**40,07%**	

Appendix E: Picks from pull-out units (440)

Table E1. The least picks from BPU 440.

BPU 440	Max units for bin	Bin	Weight per unit		L2	L3	P1	P2	P3	P4	P5	P9	U1	U2	U9	Total
90518–7758	0	0	0,76					1								1
90503–3190	0	0	0,737				1									1
90522–0152	0	0	1,737					1								1
2880564–0101	60	P3	1						2							2
90530–2332	0	0	0,618	3												3
90513–2105	0	0	1,28	3												3
90512–8694	0	0	0,385											3		3
6-32142 2472 1	16	P4	9						3							3
6-34144 7991 1	1000	P1	0,115				4									4
6-31317 0884 1	120	P2	1,614				2		2							4
90521–0473	0	0	14,2							5						5
6-31801 9497 2	2000	U2	0,14										7			7
6-9611 30 9614	0	0	0,075				8									8
6-191652 00	0	0	0,102									8				8
6-31801 9497 1	600	U9	0,084									8				8
90521–0470	0	0	9,7							8						8
90522–0150	0	0	1,73					8								8
90516–3207	0	0	1,665									8				8
6-9613 41 9801	120	P4	1,089						8							8
6-31317 0895 8	400	P9	0,36									9				9
6-191001 00	0	0	0,056							11						11
6-9613 41 8104	40	P1	0,633									11				11
6-9613 40 9410	720	P1	0,146				12									12
6-34144 6193 1	100	P1	0,65				12									12
6-31356 6141 1	10	P4	10,241							12						12
6-9611 31 0061	40	P2	1,618					13								13
6-31801 9971 3	36	P4	3,52				14									14
6-32360 0090 2	12	P4	1,9							14						14
6-31801 9497 3	1200	P1	0,155				15									15
6-190996 00	0	0	0,055				15									15
6-1995 101 056	600	P1	5,538				16									16
6-31801 9498 2	800	U1	0,16				16									16
6-31317 0817 3	0	0	1,32				16									16
6-32360 0090 1	0	0	1,246						16							16
6-190994 00	0	0	0,02				16									16
90521–0472	0	0	9,7							16						16
6-990354 15	0	0	0,468					17								17
6-190613 00	0	0	0,12				18									18
90511–2966	0	0	0,933					18								18
90521–5566	0	0	1,795											18		18
90521–1936	0	0	0,013							18						18
6-31317 0895 7	500	P9	0,1									18				18
6-9613 40 9411	600	P1	0,24									19				19

Table E2. Most picks from BPU 340.

BPU 340	Max units for bin	Bin	Weight per unit	P1	P2	P3	P4	P9	U9	Z2	Z4	Total
6-9612 93 9303	400	P9	0,159					117				117
6-34144 6195 1	150	P1	0,66	41	19							60
90526–2330	0	0	3,479	39	15	3						57
6-990006 01	0	0	1,055	55								55
6-9613 13 8804	50	P9	0,674					53				53
90521–4692	0	0	2,135	5	6			38				49
6-31801 5044 1	160	P1	3,795	24	23							47
6-34568 7490 1	100	P1	0,995	30				16				46
6-990006 04	0	0	2,264	44								44
6-9611 44 4511	132	R5	0,735	44								44
90526–2332	0	0	8,732	27				15				42
90513–3130	0	0	3,861	25	15	1		1				42
90521–0475	0	0	23			33				4		37
90516–9830	0	0	0,502	28	4			3		2		37
6-34144 6196 1	140	P1	1,89	37								37
90511–4904	0	0	4		4	32						36
6-990006 06	0	0	3,3	35								35
344253–0150	0	0	0,569	35								35
90521–7267	0	0	13		29	5						34
6-34144 8482 1	100	P1	3	34								34
90521–0478	0	0	27			29				4		33
90522–6109	0	0	2,36					33				33
90513–3131	0	0	6,207		31	2						33
90521–0476	0	0	23			30				2		32

Table E3. Least picks from HP 440.

HP 440	Max units for bin	Bin	Weight per unit		P1	P2	P3	P4	P5	P9	U1	U2	U7	Total
6-4723 1783 01	20	P1	1,36		1									1
6-4722 6075 01	100	P5	2,899				2							2
6-4722 5848 01	100	P2	1,1			2								2
6-4722 9559 23	36	P2	6,423			3								3
6-4722 7071 01	40	P1	5,636				6							6
6-4722 6396 02	16	P5	4,825					7						7
6-4722 6301 01	55	P2	1,99		8									8
6-4722 5924 02	0	0	30,71	9										9
6-4722 2919 01	60	P1	2,622		10									10
6-4722 2222 01	100	P1	4,923		12									12
6-4722 7155 02	400	P1	1,41		12									12
6-4722 9892 01	40	P2	0,828		14									14
6-4723 2187 80	15	P5	7,731						15					15
6-4723 0585 01	80	P3	0,343				15							15
6-4722 1988 01	400	P2	0,201			16								16
6-4722 0312 01	100	P1	1,671		16									16
6-4722 5415 01	0	0	3,2										17	17

6-4722 5537 02	100	P1	5,166								17			17
6-4722 7087 01	100	P1	2,85		18									18
6-4723 2187 81	15	P5	6,844						19					19
6-4722 6852 46	200	P2	0,58			19								19

Table E4. Most picks from HP 140.

HP 140	Max units for bin	Bin	Weight per unit	P1	P2	P3	P4	P5	P6	P9	Total
6-4016 0302 70	0	0	0,356	89							89
6-4723 2294 01	30	P1	19,54	68	3						71
6-4722 1232 03	11	P2	0,1	7	51		12				70
6-4722 1230 03	15	P1	14,195	61			8				69
6-4241 0010 51	36	P3	18,52	15	44		10				69
6-4723 0461 01	85	P2	4,48	69							69
6-4723 2300 01	200	P1	1,84	65							65
6-4723 2301 01	50	P9	1,7							65	65
6-4722 7643 02	10	P1	22,9	48		9	7				64
6-4723 2293 01	40	P1	3,94	63							63
6-2110 55	0	0	0,345	60							60
6-4723 0428 80	50	P2	1,976	9	42	6					57
6-4723 2291 01	10	P2	50,4		50		7				57
6-4722 5957 05	70	P1	9,355	54							54
6-4722 7644 80	15	P1	16,2	46		2	6				54
6-4723 1337 01	25	P1	1,2	48							48
6-4722 7880 01	27	P1	3,315	47							47
6-4722 7807 01	100	P2	0,92	47							47
6-4722 7651 01	40	P1	6,2	47							47
6-4722 7815 01	60	P1	3,594	47							47
6-4722 7240 01	50	P1	1,697	46							46
6-4722 5265 32	32	P2	6		42					4	46
6-4722 7652 01	40	P4	6			46					46
6-4723 1413 01	100	P9	0,235							46	46
6-4722 0313 02	24	P2	28,28	17	28						45
6-4241 0204 10	20	P2	12,265		45						45
6-4723 2292 01	10	P1	17,3	44							44
6-4722 0752 01	80	P1	3,928	29						12	41
6-4723 0849 80	30	P2	4,62	41							41
6-4723 0630 01	40	P1	7,308	38		2					40
6-4722 9353 03	60	P1	7,52	38							38
6-4722 7647 01	218	P3	1,2	13	24						37
6-4723 2535 80	24	P2	14	5	10	12	7				34
6-4723 2540 02	12	P1	12,9	26			6				32

Table E5. Least picks from HT 440.

HT 440	Max units for bin	Bin	Weight per unit		P1	P2	P3	P4	P5	Total
6–1 648 336 10	52	P4	5,42					3		3
6–1 648 179 01	84	P5	6,158			4				4
6–1 648 336 09	83	P5	5,229					8	4	12
6–1 648 336 06	300	P5	3,213						14	14
6–1 648 336 07	162	P5	3,516						19	19

Table E6. Most picks from HT 240.

HT 240	**Max units for bin**	**Bin**	**Weight per unit**	**P1**	**P2**	**P3**	**P4**	**P5**	**P9**	**Total**
6-1 647600 05	0	0	0,838	55		22	1			78
6-990397 18	0	0	0,044	30					37	67
6-990397 16	0	0	0,017	44					6	50
6-1 648346 21	400	P2	0,38	41						41
6-1 647616 02	0	0	3,685		32	6				38
6-990340 37	0	0	0,735		28	8				36
6-990354 05	0	0	0,443	31						31
6-1 647600 01	0	0	0,51	31						31

Table E7. Least picks from heavy 440.

Heavy 440	**Max units for bin**	**Bin**	**Weight per unit**		**P1**	**P2**	**P3**	**R5**	**Total**
6-4722 5914 04	12	P2	14,57	2					2
6-4722 5924 04	0	0	6,179	2					2
6-4722 5915 04	0	0	17,52	2					2
6-4722 6104 04	0	0	0	3					3
6-4723 3047 01	22	P1	27,7		3				3
6-4722 5924 03	6	P2	1	3					3
6-4722 5920 01	0	0	17	4					4

Table E8. Most picks from heavy 440.

Heavy 640	**Max units for bin**	**Bin**	**Weight per unit**	**P1**	**P2**	**P3**	**P4**	**Total**
6-4722 8644 01	31	P1	1,01	23				23
6-4722 6846 01	5	P3	125		5	13		18
6-4722 9588 23	12	P3	30				15	15
6-4723 2661 01	5	P3	119			14		14
6-4722 7145 01	31	P1	19,54	14				14
6-4722 6842 01	6	P3	108			13		13
6-4722 7392 01	8	P1	100,2	11				11
6-4723 0970 01	21	P2	29,72		11			11

Appendix F: Picks from heavy pallet lift 62 (620)

Table F1. Most picks for heavy lift 620.

620	Max units for bin	Bin	Weight per unit		K1	K2	L1	L2	L3	L4	P1	P4	P9	Total
6-4648 0000 05	0	0	0,002			147								147
6-4722 2455 01	200	L1	0,165				129							129
90459-0277	0	0	0,005	124										124
312101-0536	0	0	0,036	113										113
6-4723 1251 03	0	0	0,026					108						108
6-4722 8082 03	0	0	0,474						95					95
6-4722 7661 01	0	0	0,091					80						80
6-4722 6781 01	200	L4	0,453							80				80
6-4722 6783 01	128	P1	1,42								80			80
6-4723 1251 06	0	0	0,037								80			80
315402-0186	0	0	0,008				72							72
6-4722 7650 01	0	0	0,3					70						70
312101-0629	0	0	0,094								69			69
6-4302 0260 02	300	L1	0,014				69							69
6-4302 0355 01	0	0	0,027				69							69
6-4305 0020 00	0	0	0,236					69						69
312155-0382	0	0	0,011				69							69
6-4016 0309 61	0	0	0,675					69						69
90459-6662	0	0	0,011				69							69
315401-0178	0	0	0,003	67										67
6-4722 8764 01	0	0	0,082	67										67
312101-0538	0	0	0,04	67										67
312105-0455	0	0	0,015				59							59
6-4722 7365 01	0	0	0,036					58						58
312105-0499	0	0	0,031					52						52
312115-0449	0	0	0,012				52							52
90087-0024	0	0	0,045	52										52
315106-0204	0	0	0,049				51							51
6-4723 0695 01	0	0	0,818	50										50
6-4722 7655 01	0	0	0				46							46
6-4722 7654 01	0	0	0,17				46							46
6-4722 7658 01	0	0	0				46							46
6-4722 7659 01	0	0	0				46							46
6-4722 7660 01	0	0	0				46							46
6-4722 7656 01	0	0	0			46								46
342747-0109	0	0	0,156					46						46
6-4722 7657 01	0	0	0				46							46
90459-6526	0	0	0,25					46						46
6-4722 7646 01	150	P1	2,603								43			43
6-223412 80	0	0	0,016					42						42
6-4722 5174 01	0	0	0,069				39							39
6-4016 0302 15	100	L3	0,241										39	39
312104-0506	0	0	0,048	39										39
6-4722 6077 02	0	0	10,38	22							7			29
6-4016 0302 70	0	0	0,356	5				19						24

Table F2. Over 15 picks between sep 2021 to feb 2022 from 140, 240, 340 and 440 that have storage unit type P1 and weigh more than 5kg.

Material	Pallet zone	Storage type	Max weight	Max units for bin	Bin	Picks	Weight per unit
6-4723 1911 01	11	440	74	10	P1	161	7
6-4723 1791 01	13	440	159	30	P1	72	5
6-4722 7649 01	13	440	320	40	P1	69	8
6-4722 7146 01	40	440	410	60	P1	69	7
6-4723 2294 01	11	140	586	30	P1	68	20
6-4722 1230 03	11	140	213	15	P1	61	14
6-4722 9322 04	13	440	336	60	P1	56	6
6-4722 5957 05	11	140	655	70	P1	54	9
6-4722 7041 01	11	440	519	100	P1	53	5
6-4723 3045 02	13	440	240	30	P1	52	8
6-4722 7643 02	11	140	229	10	P1	50	23
6-4722 7651 01	12	140	248	40	P1	47	6
6-4722 7644 80	11	140	243	15	P1	46	16
6-4723 2292 01	11	140	173	10	P1	44	17
6-4722 9353 03	11	140	451	60	P1	38	8
6-4723 0630 01	12	140	292	40	P1	38	7
90513–3139	30	440	0	0	0	31	6
6-4723 2291 05	11	140	401	8	P1	31	50
6-4722 5265 25	13	140	216	36	P2	29	6
6-4723 0531 80	11	140	221	12	P1	28	18
6-4723 2542 02	12	140	168	20	P1	28	8
6-4723 0632 01	12	140	274	40	P1	27	7
90526–2332	31	340	0	0	0	27	9
6-4723 0535 02	12	140	83	12	P1	26	7
6-4723 2540 02	12	140	155	12	P1	26	13
6-4723 0631 01	40	440	577	28	P2	23	21
6-4723 4023 01	12	140	0	0	0	21	7
6-9613 15 4804	30	440	354	41	P3	20	9
6-4723 0359 02	11	140	206	33	P1	20	6
6-9613 18 5431	32	340	158	24	P2	19	7
6–1 648399 09	21	240	292	40	P1	19	7
6-4723 3045 05	12	140	315	35	P1	18	9
6-4722 7086 01	40	440	378	40	P1	18	9
6-4723 0355 80	12	140	294	48	P1	18	6

6-4722 9353 04	11	140	651	70	P1	18	9
6-4722 9353 05	12	140	497	45	P1	17	11
6-4722 0313 02	11	140	679	24	P2	17	28
6-4722 2022 01	13	140	344	30	P1	17	11
6-4722 9658 01	11	140	400	25	P2	17	16
6-4723 2673 01	11	140	712	40	P1	16	18
6-4722 0311 02	12	140	240	30	P1	16	8
6-1995 101 056	22	440	3 323	600	P1	16	6