Emma Elisabeth Farstad Cherrie and Sofie Aasheim

Dynamic Storage Location Assignment Using Operator Idle Time for Reshuffling of Goods in a Manually Operated Warehouse

Master's thesis in Engineering and ICT
Supervisor: Anita Romsdal
Co-supervisor: Fabio Sgarbossa
June 2022

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TPK4930 Master Thesis

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Acknowledgment

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E.C. & S.A

Abstract

As the third-party logistics (3PL) market has grown in the past decades, the competition in the industry has increased as well. Thus, 3PL providers must be smarter in their operations to reduce costs and stay competitive. For 3PL warehouses, order picking is considered as the most time-consuming and labor-intensive activity. It also involves the biggest warehouse expense, accounting for approximately 55 % of the total warehouse operating cost. One way to reduce costs and stay competitive is therefore to improve the order picking process. Traveling in the warehouse is what consumes most of the time related to order picking, so reducing the travel time can increase the efficiency of the order picking process. The travel time can be reduced by minimizing the travel distances, and a possible way to do this is by reshuffling goods during idle time to more convenient storage locations. In in the fast-moving consumer goods (FMCG) industry, the products usually have variable demand and are produced in high volumes. Thus, the most suitable storage locations for different FMCG products varies as well, and a dynamic storage policy with goods reshuffling can be a good solution for warehouses in this industry. This thesis attempts to identify the key challenges and improvement areas of the order picking process, and the potential benefits of dynamic storage policies and goods reshuffling. Then, possible applications of goods reshuffling are suggested to improve the order picking process through use of warehouse data. This is done through both a literature study and a single-case study of a 3PL warehouse provider, Leman. Several challenges with the order picking process for both Leman and warehouses in general were identified, and improvements through use of goods reshuffling were discussed based on different data analyses and travel time estimations. The previous research on goods reshuffling in manually operated warehouses was very limited, but some possibilities were discussed based on the literature concerning dynamic storage policies, automated reshuffling, and the results from the case study. However, due to the case study only focusing on a single case, it is difficult to generalize the findings. Further work on the topic includes an investigation of continuous goods reshuffling and reshuffling in other areas within the warehouse such as the inbound/outbound (I/O) area.

Sammendrag

Ettersom markedet for tredjepartslogistikk (3PL) har vokst de siste tiårene har konkurransen i bransjen også økt. Derfor må 3PL-leverandører være smartere i driften for å redusere kostnadene og forbli konkurransedyktige. For 3PL-lagere anses ordreplukking som den mest tid- og arbeidskrevende aktiviteten. Den innebærer også den største lagerutgiften, og utgjør omtrent 55 % av de totale driftskostnadene. En måte å redusere kostnader og holde seg konkurransedyktig på er derfor å forbedre ordreplukkingsprosessen. Reising inne på lageret er det som utgjør mesteparten av tiden knyttet til ordreplukking, så å redusere reisetiden kan øke effektiviteten i ordreplukkingsprosessen. Reisetiden kan reduseres ved å minimere reiseavstandene, og en mulig måte å gjøre dette på er å omstokke varer ved ledig tid til mer praktiske lagerlokasjoner. I industrien for hurtiggående forbruksvarer (FMCG) har produktene vanligvis varierende etterspørsel, og de produseres i store volum. Dermed varierer også de mest passende lagerlokasjonene for ulike FMCG-produkter, og en dynamisk fordelingsmetode for lagerlokasjoner med vareomstokking kan være en god løsning for lagere i denne bransjen. Denne oppgaven forsøker å identifisere nøkkelutfordringene og forbedringsområdene i ordreplukkingsprosessen, og de potensielle fordelene med dynamiske fordelingsmetoder og vareomstokking. Deretter foreslås mulige anvendelser av vareomstokking for å forbedre ordreplukkingsprosessen gjennom bruk av lagerdata. Dette gjøres gjennom både et litteraturstudie og et enkelt casestudie av en 3PL-lagerleverandør, Leman. Det ble identifisert flere utfordringer med ordreplukkingsprosessen for både Leman og lagere generelt, og forbedringer gjennom bruk av vareomstokking ble diskutert basert på ulike dataanalyser og reisetidsestimater. Den tidligere forskningen på vareomstokking i manuelt opererte lagere var svært begrenset, men noen muligheter ble diskutert basert på litteraturen om dynamiske fordelingsmetoder for lagerlokasjoner, automatisert omstokking og resultatene fra casestudiet. På grunn av at casestudiet kun fokuserer på ett enkelt tilfelle er det vanskelig å generalisere funnene. Videre arbeid rundt temaet inkluderer en undersøkelse av kontinuerlig vareomstokking og omstokking i andre områder av lageret som for eksempel området for inngående/utgående varer.

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Chapter 1

Introduction

This chapter introduces the background and motivation for the project, followed by a description of the problem statement. Then, the research purpose, research objective, and scope are outlined. Lastly, an overview of the thesis structure is provided.

1.1 Background and Motivation

The complex network of the fast-moving consumer goods (FMCG) industry covers a series of industrial activities such as production, distribution, packaging, warehousing and transportation of goods (Ali et al., 2020). The products of FMCG have high demands and high volumes, a short life cycle and low-profit margins. Due to economic globalization and increasing customer demands, the industry is experiencing a significant increase in competition (Radosevic et al., 2013). This has led to many FMCG companies outsourcing their logistic activities to third-party logistics (3PL) providers to focus on their core activities. 3PL providers specialize in providing logistic activities and services, such as warehousing and transport. One of the most common types of 3PL providers are those who offer the service of external warehousing (Borgström et al., 2021). These types of 3PL providers are the intermediary between manufacturers and their customers. They are responsible for all activities related to their warehousing processes such as storing, picking, packing, and shipping their goods (Bartholdi and Hackman, 2019). The competition among 3PL providers is becoming increasingly fierce, due to growing customer expectations regarding the services offered; i.e. short delivery time, high flexibility and low costs (Tipping, 2019). As a consequence, 3PL providers need to constantly find ways to improve their operations and reduce costs, in order to ensure their continuance.

There are several ways to optimize the different activities in a warehouse. The most time-consuming, and thus expensive warehouse operation is order picking, accounting for about 55 % of the time allocated to all warehouse activities (Valle et al., 2017). Improving the efficiency of order picking can therefore have a huge impact on the total warehouse performance and expenses. The efficiency of an order picking process depends on the storage locations of the goods because this is what decides the travel time. The travel time for an order picking process is defined as the time it takes to travel within the warehouse from the in- and outbound (I/O) area to the storage location: the closer to the I/O area the goods are stored, the shorter the travel time. Travel time is considered as the main source of waste in a warehouse (Kofler, Beham, S. Wagner and Affenzeller, 2014), and it is what consumes most of the time related to order picking (Tajima et al., 2020). To optimize the order picking process, it is therefore essential to investigate the travel time and storage locations.

1.2 Problem Statement

Most research on storage location assignment are based on item demand (Brynzér and Johansson, 1996). However, the primary focus in the literature is on static storage policies, meaning that the storage locations are permanent and do not change (Gu et al., 2007). In addition, it is often assumed that all incoming and outgoing shipments are known. For real-world scenarios in the FMCG industry, this is rarely the case. The volumes of both incoming and outgoing goods usually have large variations over time (Ali et al., 2020). Additionally, the shipments are often unpredictable due to challenges with planning and information sharing through the supply chain. A static storage policy is therefore not optimal as it does not provide any functionality for handling variable demand (Li et al., 2016). As the demand changes, the storage locations should be updated as well so that the products with highest demand are stored nearest the I/O area, and vice versa. The phenomenon of changing the storage locations of goods in a warehouse is called dynamic storage assignment and can be performed randomly or based on variables such as demand(L. Chen et al., 2011). The implementation of dynamic storage assignment can shorten the travel distances, and thus, the travel time and total lead time, which can lead to a better overall warehouse performance.

In situations with dynamic storage locations, there are two options for how the locations of the products are updated (Kofler, Beham, S. Wagner, Affenzeller and Achleitner, 2011). The first option is only updating the storage locations on incoming goods. This means that once an item arrives at the warehouse, its storage location remains the same until it leaves the warehouse. The second option is known as warehouse reshuffling. Warehouse reshuffling is a reorganization strategy that consists of physically relocating goods from an initial storage location to a new storage location inside the warehouse (L. Chen et al., 2011). In the literature, most research on reshuffling concerns automated warehouses. This implies that the reshuffling process is performed by automated storage- and retrieval systems (AS/RS), often performed by robots outside the working hours, i.e., during the night. However, small and medium-sized enterprises (SMEs) may lack resources for implementing such automated reshuffling systems (Ballantine et al., 1998). This project will therefore investigate manual warehouse reshuffling done by warehouse operators during the working hours.

1.3 Purpose and Objective

The aim of this project is to investigate how manual reshuffling of goods during idle time can affect the order picking process for a 3PL provider of warehousing services. This is done through a literature study and a case study of an SME-3PL provider in the FMCG industry. The following research questions are investigated and discussed:

RQ1: *What are the potential benefits of dynamic storage location assignment and reshuffling?*

The purpose of this research question is to identify the potential benefits of having a dynamic storage policy and implementing reshuffling in a warehouse to understand how this can possibly improve the order picking process. This was achieved through a literature study of previous research on order picking, dynamic storage location assignment, and reshuffling.

RQ2: *Which methods for reshuffling can be suitable for manually operated warehouses?*

The purpose of this research question is to identify different types of reshuffling in warehouses, and decide which methods can potentially be most suitable for manually operated warehouses. This done to find the best reshuffling methods for improving the order picking process. This was achieved through a literature study of previous research on warehousing and warehouse reshuffling, along with a case study with a reshuffling analysis.

RQ3: *How can warehouse data be applied to make decisions about reshuffling in manually operated warehouses?*

The purpose of this research question is to investigate how different types of data from the warehouse can be analyzed and applied in the decision making process for reshuffling in a manually operated warehouse. This was achieved through execution of different data analyses on data from the case study.

The research objective in this thesis is divided in two parts:

1. Conduct a systematic literature study:
   (a) Identify the key challenges and improvement areas of warehouse order picking.
   (b) Identify common warehouse storage policies and current research on goods reshuffling.
2. Conduct a case study of a 3PL warehouse provider, Leman:
   (a) Analyze the current situation at Leman to identify the key challenges of their order picking process.
   (b) Use warehouse data from Leman to investigate the opportunities for manual goods reshuffling during idle time.
   (c) Provide order picking improvement suggestions through use of manual goods reshuffling.

1.4 Scope

The scope of this thesis is to study dynamic storage location assignment and reshuffling for an SME-3PL provider of warehousing services in the FMCG industry. The focus is on manually operated warehouses. The reason for focusing on small, manually operated warehouses is because it was identified a research gap in this field. Some research on dynamic storage location assignment and reshuffling was found, but this mainly concerned automated warehouses (G. Chen et al., 2021). In smaller countries such as Norway, the warehouses are often smaller and can therefore often not afford to implement automated warehouse solutions (Olsen, 2018). Thus, it can be beneficial to have more knowledge about how to improve manual warehouse operations.

This study focuses on reshuffling during idle time. This is because the existing literature on manual goods reshuffling is very limited. As reshuffling during idle time will will not require any major changes to the normal warehouse operations, it is easier to implement and test, and it is therefore a good place to start. The study concerns investigating conceptual methods for reshuffling and how the travel time potentially can affect the order picking process through analyses of warehouse data. The focus is not on specific mathematical models or on optimization of goods reshuffling.

1.5 Thesis Structure

The structure of this thesis is shown in Table 1.1.

Chapter	**Description**
Introduction	Introduces the background and motivation for the thesis and describes the problem statement and the research purpose, research objective, and scope.
Research Methodology	Describes the methodology used in the research process, how the qualitative and quantitative information was gathered, and how the data analyses were performed.
Theoretical Background	Investigates existing literature and current research on the topic, and explains the key theoretical perspectives relevant to the thesis. The topics include supply chains, warehousing, 3PL, storage assignment policies, order picking, and reshuffling.
Case Study	Investigates a 3PL warehouse provider, Leman, and their order picking process. The current situation at Leman is mapped with a detailed description of their warehouse layout, principles, operations and activities, WMS and costs. This is followed by an analysis of the current situation, a reshuffling analysis, and several proposals based on these analyses.
Discussion	Combines the theoretical background with the case study to discuss the three research questions.
Conclusion	Summarizes the thesis' key takeaways and examines possible future work.

Table 1.1: Thesis structure.

Chapter 2

Research Methodology

The research methodology consists of a literature study and a case study. This chapter presents and describes the research process, the research design, the data collection, and the analyses performed.

2.1 Literature Study

In this thesis a systematic literature review was performed, to get an overview of the topics and trends related to the initial problem statement, and to identify trends and gaps in the research areas. In addition, the literature study provided the researchers with more in-depth knowledge about the topic (Ridley, 2012). The literature study started with a wide scope to get more insight into relevant subtopics related to the problem statement. To obtain some general knowledge about warehousing, three books about the topic, (Bartholdi and Hackman, 2019), (Richards and Gwynne, 2014) and (Kay, 2015), were read. This was also useful for learning relevant terms and search words for the literature study. Additionally, the three books were used for some descriptions of general warehousing topics in the theory section of this thesis.

The next step was to read relevant research about topics concerning the problem statement such as supply chains, fast-moving consumer goods, 3PL providers, warehousing, storage policies, picker routing, travel time estimation and warehouse reshuffling. Investigating these topics in the existing literature, made it easier to narrow down the scope and find the best existing methods. It also made it possible to identify current research trends and research gaps.

The articles read in the literature study were found by using the search engines Google Scholar, Science Direct, Scopus, and Web of Knowledge. The number of citations and the types of journals of publication were considered when searching to ensure validity and quality of the articles. Table 2.1 shows all search words used during the searching process. Synonyms of the listed words, along with acronyms and abbreviations, were also used to ensure that all relevant versions of the terms were included. This was also to make sure that the search was as broad as possible. As the study progressed and new information came to light, these terms were updated several times. To avoid irrelevant papers, Boolean operators were used in the search between keywords.

To identify relevant papers, the abstract was read first. All papers identified as relevant based

Primary search words	Additional search words
supply chain	fast-moving consumer goods, flexibility
third-party logistics	trends, challenges, warehousing
warehousing	operations, challenges, storage policies
storage	assignment, policies, classifications, locations
dynamic storage location assignment	policies, optimization, estimation, minimization
travel time	minimization, optimization, order picking, automation
warehouse reshuffling	automated, manual, idle time, continuous

Table 2.1: Search terms used for the literature study.

on the abstract were then entered into a detailed log book and the citation tool Mendeley was used as a reference manager. The most relevant papers were read more carefully as the study progressed. Citation search was also used on the most relevant papers to gain a deeper understanding of them.

The main limitation of the literature study is the complete reliance on previous research, as well as the restricted amount of previous literature on the topic in question. In addition, the researcher bias will result in some subjectivity, which may influence the findings.

2.2 Case Study

To better understand warehousing and to achieve the research objective, a single case study was performed. The case research method was applied to examine the phenomena within the real-world context. Conducting a single case study was beneficial, because it provided the researchers with additional research depth. The case study focused on an SME, Leman, which is a 3PL provider of warehousing services. Leman has a manually operated warehouse facility located in Vestby, in Norway, which was investigated. The main reason for selecting this company is that Leman is a part of the DigiMat project, which this thesis is also a part of. This made it easier to gain access to information about the company and relevant data. Additionally, Leman was a relevant company for investigating reshuffling in a manually operated SME-3PL warehouse provider.

To prepare for the case study, previous work on the same case company was read to gain more knowledge about the situation. This includes a specialization project, (Singh Pannu et al., 2020), three master theses from NTNU, (Myhr, 2020, Pannu, 2021 and Byfuglien, 2021), and a project report written by a group of Danish students from Aalborg University, (Leon et al., 2019). Parts of the information from these reports were also used in this case study as secondary data. To ensure that the information was correct, and still valid, it was checked with Leman before it was used as secondary data.

During the project period, both qualitative and quantitative data was collected. This also included a visit to Leman's facility in Vestby. The qualitative data involves meetings, tours, interviews, and operations. The interviews conducted were semi-structured, a format that is especially suitable for an exploratory, evaluation and explanatory type of research (Matthews and Ross, 2010). This matches the aim of this study. Additional reasons for this choice of method are that semi-structured interviews:

- Includes an interview guide.
- Allows for additional questions.
- Are adaptable.
- Consists of open-ended questions, that provoke the interview participants to give multi-statement answers in their own words.

A case study protocol and an interview guide, were designed with the purpose of assisting the researchers, so that all necessary topics were covered. The case study protocol are presented in Appendix B and the interview guide in Appendix C. The interviews were recorded, and after the interviews were conducted, the recordings were transcribed to obtain a thorough understanding of the data and ensure that no details were overlooked. The transcribed interviews and a summary of the results were also verified by the interview participants to avoid interpretation mistakes on the researchers side.

The quantitative data included in this study, involves all the different types of data used for the data analyses during the case study. The data collection is described in detail in Table 2.2 (qualitative data) and Table 2.3 (quantitative data).

Format	**Actor(s)**	**Description**	**Date**
Zoom meeting	Supply chain director (Brynild) and DRIW	Discussion of topics and ideas	01.10.2021
Guided tour	Warehouse manager (Leman)	Tour of Leman's facility in Vestby	07.04.2022
Interviews	Operators	Interviews with several warehouse operators about their daily activities, and the order picking process	07.04.2022
Observations	Warehouse and operators	Observations of the order picking process, and other warehouse activities	07.04.2022
Interview	IT manager (Leman)	Semi-structures interview with the IT manager at Leman about the layout, storage locations, WMS, order picking, etc.	08.04.2022

Table 2.2: How and when qualitative data about the case study was gathered.

(Matthews and Ross, 2010) identifies several limitations of the semi-structured interview method that may have affected the research conducted in this study. These limitations are:

Format	**Actor(s)**	**Description**	**Date received**
KPI reports	Supply chain director (Brynild)	Brynild's KPI measurements of Leman	25.10.2021
Transaction data 01.06.18-12.03.21	Supply chain director (Brynild)	Leman's transactions concerning Brynild's products from 01.06.18 to 12.03.21	25.10.2021
SKU data 12.03.2021	Supply chain director (Brynild)	Storage data about all SKUs stored at Leman 12.03.2021	25.10.2021
Layout	Warehouse manager (Leman)	Layout of Leman's facility in Vestby	24.11.2021
Price structure	Warehouse manager (Leman)	Overview of all prices Leman charges Brynild for their logistics activies	24.11.2021
WMS manual	IT manager (Leman)	The user manual for the WMS Astro used at Leman	10.03.2022
Transaction data 2021	IT manager (Leman)	Leman's transactions concerning Brynild's products for 2021	10.03.2022
SKU list	IT manager (Leman)	List of all SKUs from Brynild with relevant information	02.05.2022
Detailed layout data	IT manager (Leman)	Detailed information about the layout with racks, bays and shelves with numbers and locations	02.05.2022
ABC classification data	IT manager (Leman)	Information about where all classes are located in the warehouse	02.05.2022

Table 2.3: How and when quantitative data about the case study was gathered.

- The method is time consuming.
- The interview is highly dependent on the researcher's interview skills.
- The researcher risks guiding the interview participant.
- The open-ended nature of the questions allows the interview participant to focus on irrelevant topics.

Another weakness of the case study is that only a single case study was performed. This is, as previously stated, beneficial because it allows for a more thorough investigation of the case in question. However, including multiple case studies would have been beneficial, and could provide more reliability and generality to the findings of the study (Gustafsson and Johanna Gustafsson, n.d.).

2.2.1 Data Analysis

To better understand the order picking process and the issues and opportunities regarding reshuffling in a warehouse, several data analyses were executed in the case study. There were mainly four types of data used in the analyses:

- **Transaction data:** Data from the WMS containing rows of transactions for each operation performed in the warehouse over a period of time. This data set contained 51 columns and 268 418 rows, and the time period was from 04.01.2021 to 30.12.2021. Additionally, corresponding data sets for 2019 and 2020 were used for some of the analyses.
- **Location data:** Information about all the locations in the warehouse, including rack numbers, bay numbers and shelf numbers. This also included warehouse layouts and rack layouts.
- **ABC classification data:** Information about the locations of the different storage location classes A, B and C within the warehouse.
- **Stock-keeping unit data:** Information about each single SKU stored in the warehouse during the chosen time period, including the initial inventory level for each SKU and the number of SKUs for filling one pallet.

All analyses were performed in Visual Studio Code, using the programming language Python. The data analysis Python-library *pandas* was used for data pre-processing and for most of the analyses. The Python graphing library *Plotly* was used for creating all plots and graphs in the project.

The transaction data set described above was used as the main data source for most analyses. This data set was received from Leman in Excel format, and to make it more compatible with Python and *pandas*, it was converted to .csv format. Due to the large amount of columns and rows, the data had to be pre-processed before the analyses. Many of the columns were not in use by Leman, and these were removed. Additionally, only the transactions regarding the order picking activities were included, and only items from the classification zones A, B and C. After cleaning the transaction data, the remaining columns contained information about transaction type, date and time, pallet type, amount, storage location, zone and article number. The parameters and their value types are shown in Table 2.4.

Parameter name	**Type**	**Description**
Reg-dato	DateTime object	The date and time of the transaction (DD-MM-YYYY HH:MM:SS)
Logg-kode	int	Type of transaction (receiving, picking, moving etc.)
Funksjonstype	int	More specific type of transaction (e.g. if Logg-kode is 4 (picking), then Funksjonstype is either 7 (carton picking) or 8 (full pallet picking)
Antall	int	Amount (in cartons)
Fra-hylle	int	Rack number (24-41)
Fra-X	int	Bay number (011-223)
Fra-Y	int	Shelf number (1-8)
Sone	str	Zone (A, B or C)
Artikkelnr	int	Article number

Table 2.4: The parameters in the transaction data set after the data pre-processing and cleaning.

Chapter 3

Theoretical Background

This chapter presents the necessary theoretical background for this thesis. First, supply chains and FMCGs are introduced followed by a description of the food sector. Then, warehousing with its operations, performance, and management systems is described. Then follows a description of third-party logistics providers and the challenges they commonly face. Then, the SLAP is described and different storage policies are identified, followed by a closer description of the order picking process. Finally, warehouse reshuffling is investigated.

3.1 Supply Chains

A supply chain is a network that connects organizations with each other (Mentzer et al., 2001). It begins with an initial supplier of raw materials, and ends with delivering a final product to the end customer. The activities of a supply chain are procurement of raw materials, conversion of raw materials to final products and distribution of final products to the market. In addition, flows of products, finances, and information are all part of a supply chain (Wang et al., 2016). The current market for supply chains is becoming more globalized, dynamic and customer driven (Duclos et al., 2003). This causes a competitive environment and increases the importance of effective and flexible supply chain management to reduce costs, maintain acceptable service levels, minimize uncertainty, and in general stay competitive (Wang et al., 2016).

Today, there are three common strategies for supply chain management: the lean approach, the agile approach, and the leagile approach, which is a combination of lean and agile (Mason-Jones et al., 2000). The lean approach focuses on the elimination of waste by removing non-value-adding processes. Lean works well for relatively stable and predictable demand and low variety products. This approach is therefore not suited in situations with volatile demand and high varieties in customer requirements. Agility, on the other hand, is characterized by flexibility and responsiveness. It origins in a business concept called flexible manufacturing systems (FMSs), focusing on automation to enable rapid changeovers, which leads to a greater responsiveness to changes in product mix or volume. Agile approaches therefore suits supply chains with high variations in product types and volumes and fluctuating demands (Towill and Christopher, 2002).

3.1.1 Fast-Moving Consumer Goods (FMCG)

Currently, fast-moving consumer goods (FMCG) form one of the most important industries in the world (Webster et al., 2006). FMCG products, therefore, are central to the market - they are a dominant part of the consumers' demands and budgets. Fast-moving consumer goods (FMCG) are defined as items that are fast-moving or sold quickly, usually at a relatively low price to a large customer base (Jacobs and Mafini, 2019). Examples of FMCG are non-durable household goods, such as packaged foods/beverages, spirits, toiletries, candies, cosmetics, tobaccos, and other consumables. Some examples of large international FMCG companies are Coca-Cola, Nestlé, Body Shop, and L'Oréal. From the consumers' perspective, FMCG are habitually purchased, have low involvement (i.e. the decision to buy requires little or no effort), low price, short shelf life, and rapid consumption (Ali et al., 2020). Due to the customers' rapid consumption, FMCG often have a strong demand and are thus produced in large volumes. This, combined with low prices, makes the products easily sold which often results in low profits for the industry. FMCG typically have highly variable demand for individual products, and they may also experience seasonal demand variations.

Today, it is important for FMCG organizations to be flexible. This is a result of how the FMCG industry is constantly changing due to consumer preferences, globalization, new technologies, and innovation (Manders et al., 2016). This leads to the consumers demanding more innovative products, which means that the businesses in this industry must produce a wide range of goods, at a high volume, quickly. The consumers are spending more in developing markets, which raises the need for FMCG organizations to expand their supply chain. In addition, the FMCG business is very competitive compared to most other markets and the customer base is usually disloyal. Thus, in order to survive in this market, the FMCG organizations must be more flexible. Flexibility, in the supply chain context, is characterized by complexity, continuous change, and uncertainty (Manders et al., 2016).

Because of the variability in the demand in the FMCG industry, there are often challenges in determining the production quantities for the different products. Due to rigid manufacturing systems and supply chain networks it can also be difficult to adjust the amounts to produce. This concept is known as volume flexibility, and is defined as the ability to produce above or below the installed capacity for a product (Singh and Acharya, 2014). Volume flexibility is especially important in the FMCG industry because in enables the organization to manage their production plan and produce more accurate amounts according to the demands. Additionally, (Bala and Kumar, 2011) identifies several common issues faced by FMCG supply chains:

- FMCG supply chains are often complex because they usually own a variety of production facilities, including co-manufacturers and co-packers.
- 3PL providers often handle distribution and logistics (usually transportation and warehousing) in FMCG supply chains, which further complicates the process.
- There is constant pressure on the FMCG sector to manufacture and supply products at the lowest price as fast as possible.
- Additionally, "dealer-owned brands" sometimes appear in the retail sector, which make them direct competitors of FMCGs.

3.1.2 The Food Sector

An important part of the FMCG industry is the food sector (Heidi C. Dreyer et al., 2016). Today, the food industry not only feeds the world's population, ensures good health and living conditions and stimulates economic growth, it also provides a livelihood for a significant segment of society. Traditionally, food producers have focused on offering high quality products at low prices to their customers, generally made-to-stock (MTS), to meet their delivery lead time expectations. The profit margins on food products are generally low, which makes it critical for the food producers to maintain high efficiency in their production and produce in large batches to keep the unit costs down. In the past few decades, there has been a trend towards more product variety, higher demand uncertainty and an increase in the sale of fresh food products with short shelf life. As a result of this, food producers have to be more flexible in their manufacturing and increase their efficiency and responsiveness to be able to respond more quickly to changes in the market (Romsdal et al., 2014).

Food supply chains are typically highly industrial and global systems, offering a variety of products and services at low prices (Heidi C. Dreyer et al., 2016). The actors in a conventional food supply chain also often have highly industrialized structures, infrastructure, systems, and processes. The supply chain typically consists of primary production, suppliers of other production inputs, such as packaging materials, and industrial production/processing unit, a wholesale/distribution unit, and retailers selling the finished products to consumers (Romsdal, 2014). Transport between the different actors in the supply chain is either arranged by the actors themselves or by third-party transport companies. Figure 3.1 illustrates such a typical food supply chain.

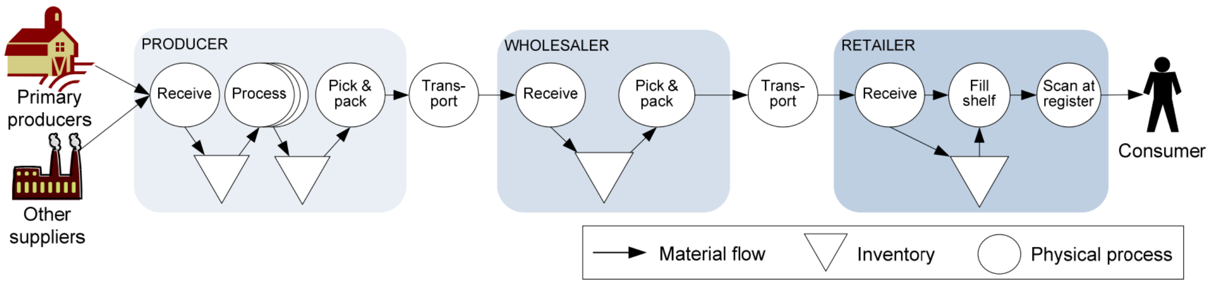


Figure 3.1: An illustration of a typical industrialized food supply chain, adapted from (Romsdal, 2014).

(Romsdal, 2014) summarizes the key characteristics of the food supply chain categorized by product, market, and production system as follows:

- **Product:**
  - *Perishability and shelf life:* High perishability and limited shelf life for raw materials, intermediates and finished products.
  - *Variety:* High variety among product types, particularly for promotions.
  - *Product life cycle (PLC):* Decreasing PLC with high failure rates for new products.
  - *Volume:* High volume of products.

- **Market:**
  - *Delivery lead time:* Customers generally demand and receive frequent deliveries, and the lead time varies by product.
  - *Demand uncertainty:* The demand is increasing and becoming more varied, mainly caused by an increasing frequency of promotional activities. The bullwhip effect also has a strong presence in the industry.
  - *Inventory management:* Limited ability to keep stock, periodic ordering, and high and stable stock-out rates. The cost of lost sales are often higher than inventory carrying costs.
- **Production system:**
  - *Production lead time:* Depends on the product, but the lead times are generally long and have a low degree of postponement.
  - *Plant, processes and technology:* Adapted to low product variety and high production volumes. Capital-intensive equipment with long set-up-times and high set-up costs.
  - *Supply uncertainty:* Some uncertainty due to seasonality and demand amplification, but generally high reliability for raw materials.

The Norwegian Food Industry

In Norway, there have been several major structural changes in the food supply chain over the past few decades (Romsdal, 2014). Many large industrial producers and brand owners have emerged, and in general, there have been a professionalization of the systems for food production, purchase, distribution, and sales. The requirements from customers and government, and the competitive situation, have made it important for companies to be more innovative and implement and develop new technology (Heidi Carin Dreyer and Strandhagen, 2008). Additionally, the market power have shifted from producers to retailers (Heidi C. Dreyer et al., 2016). In Norway today, there are generally three big retailers who manage the entire flow of products from suppliers to stores: NorgesGruppen, Coop Norge, and REMA 1000. All suppliers must meet specific logistical requirements related to packaging and distribution units as well as requirements for labeling, product volume, frequency of delivery and lead time.

3.2 Third-Party Logistics Providers

Third-party logistics (3PL) refers to the outsourcing of different logistics activities or services to a third-party business (Borgström et al., 2021). This type of business is often referred to as a 3PL provider. 3PL providers can offer a wide range of logistics services such as warehousing, transportation, inventory management, supply chain management, packaging, shipping and distribution. These services are offered to both commercial and industrial customers. A 3PL company performs these services for their customer companies and usually offers end-to-end management of specific services.

Transportation and warehousing are the two most commonly outsourced logistics activities to 3PL providers (Borgström et al., 2021). Warehouse 3PL providers offer a wide range of services, from picking and packing of goods to installing computer programs, analyzing supply chain efficiency, and managing manufacturing operations. Additionally, they coordinate and manage a part of the supply chain for the benefit of their customers, including those of their logistics suppliers and partners (Brekalo et al., 2013). As a consequence, the 3PL provider has to know the customer's business, their market situation, and the logistics and transportation they offer. As outsourcing logistics activities has increased over the past few decades, the 3PL industry has experienced a massive growth in both revenue and coverage (Premkumar et al., 2020). Today, the most common 3PL activities outsourced by companies are those that are transactional, operational, and repetitive. More strategic, IT-intensive, and customer-facing activities tend to be outsourced less frequently, despite their increasing value.

There are several reasons why a company would want outsource parts of their logistics activities to a 3PL provider. (Maloni and Carter, 2006) lists three main reasons:

1. A 3PL provider offers expertise and economies of scale leading to cost reductions for the company.
2. A 3PL provider has more focus and efficiency which leads to service improvements for the company.
3. A 3PL provider enables the company to focus on its core competencies.

Another benefit overlooked by most existing literature on 3PLs is the concept of mutually beneficial relationships between parties in the supply chain (Premkumar et al., 2020). As a result of their level of expertise, 3PL providers can offer businesses more customized service functions and a wider variety of services than basic companies. It is the 3PL provider who generates revenue while the outsourcing business receives logistics expertise. Thus, it is a beneficial relationship for both parties.

There are also several challenges commonly faced by 3PL providers identified in the literature. (Baruffaldi et al., 2020) describes three of them. First, 3PL providers often have multiple clients of varying types, where each client has its own set of requirements related to tasks and service level. Communicating with and integrating all the clients with their own activities can therefore be challenging. Second, 3PL providers often handle large variations of products due to the high number of clients. This increases the complexity of the material handling processes as the different products require different storage methods and material handling systems. Third, 3PL providers usually have to deal with unpredictable demand. The clients often have variable and seasonable demand trends which can be challenging to handle. This also makes it more difficult to accurately plan the needed capacity and workloads.

In the past few decades, the 3PL sector has seen a tremendous growth (Premkumar et al., 2020). This has lead to a high number of 3PL providers offering different logistic services, which has increased the competition in the 3PL market. To stay competitive, it has become important for 3PL providers to differentiate themselves by creating innovation (S. M. Wagner and Sutter, 2012). Examples of such innovations are new technologies and IT solutions.

3.3 Warehousing

The warehouse plays a significant role in supply chains (Bartholdi and Hackman, 2019). The term warehousing refers to the storage of goods (raw materials, work-in-progress or finished goods) at one or several points in the supply chain, where all goods received are dispatched as quickly, effectively and efficiently as possible (Richards and Gwynne, 2014). As intermediates in the supply chain, warehouses affect both costs and service, particularly because they are often the final point in the supply chain for order assembly, value-added services, and dispatching products to customers (Faber et al., 2018). Warehouses mainly add value to a supply chain in two ways (Kay, 2015):

1. **Storage:** Ensures that all products are available when and where they are needed.
2. **Transportation:** Allows for efficient collection, sorting, and distribution of products.

Warehousing is an important activity in the FMCG supply chain due to the high volumes of incoming and outgoing goods in the industry (Bala and Kumar, 2011). Even though warehousing is an expensive supply chain activity, the stock-out cost is greater than the inventory cost, and thus the warehousing activity is crucial to the FMCG supply chain. In addition, (Bartholdi and Hackman, 2019) lists the following reasons for including a warehouse in the supply chain:

- A warehouse can be useful when matching the supply to the customer demand.
- A warehouse is useful for limiting transportation costs.

On the one hand, FMCG businesses usually have high demands, which can change quickly between different products, due to for example seasonality. Supply, on the other hand, is more time consuming to change (Bartholdi and Hackman, 2019). Including a warehouse in the supply chain will allow for a quick response when the demand changes, because it provides buffering of goods. Furthermore, including a warehouse in the supply chain can reduce transportation costs. Every time something needs to be shipped, e.g., by plane or train, there is a fixed cost. A warehouse can store large amounts of goods simultaneously, which makes it possible to fill the shipments to their maximum capacity level. Thus, the cost of shipping each individual order or product will decrease.

In a warehouse, each unique product stored is called a stock-keeping-unit (SKU) (Kay, 2015). I.e., each different style, size, and color of a garment would be assigned a unique SKU. All items in the warehouse are stored in different storage locations, also called slots. A slot is a generic term for any type of storage location such as racks, bins, shelves, or floor areas. Each storage location is assigned a unique address, and multiple units of the same SKU can be stored in the same location if the capacity is sufficient.

3.3.1 Warehouse Operations

In addition to storing items, two common warehouse functions are: the repacking and the reorganization of products (Bartholdi and Hackman, 2019). The repacking of products is an important warehouse function, because as the products flow through the FMCG supply chain, the handling unit size generally decreases. Products can be repacked at different stages through the supply chain and workhouses frequently handle units in pallet and carton quantity. That is, warehouses connected to the FMCG industry usually handle both goods that must be repacked into smaller quantities and goods that are sent out in the same condition as they arrived. Note that the smaller handling unit size is, the larger the cost of material handling is, which results in downstream warehouses having larger expenses related to this.

The warehouse function of reorganizing goods consists of an inbound and an outbound process (Bartholdi and Hackman, 2019). The inbound process includes the sub-processes receiving and put-away, whilst the outbound process includes the sub-processes order-picking, checking, packing and shipping. In general, all goods should flow continuously through the sequence of sub-processes in the stated order. The main warehouse operations related to the reorganization of goods are described below and illustrated in Figure 4.1.

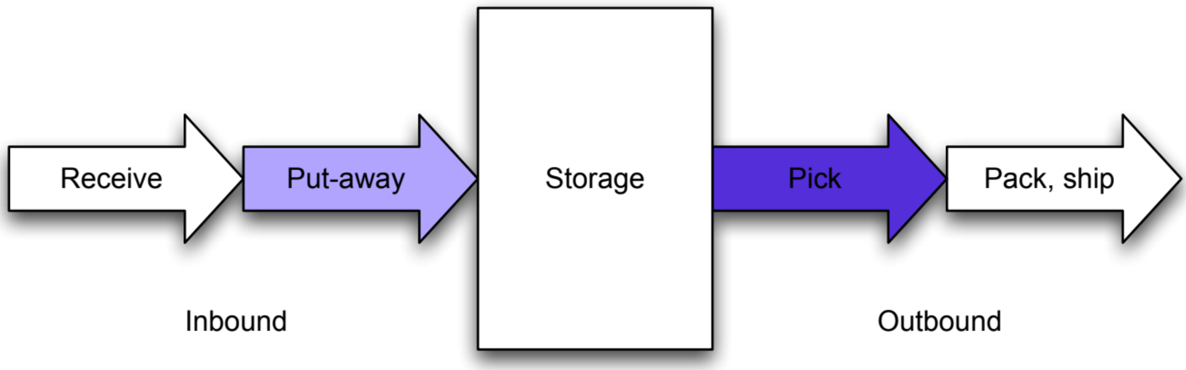


Figure 3.2: A simplified illustration of the warehouse operations, adapted from (Bartholdi and Hackman, 2019, page 24).

Receiving

The first process in a warehouse is receiving (Van Den Berg et al., 1998). This process involves all activities related to the arrival of goods and preparation for storage. This involves unloading, verification, inspection, and further preparation for put-away. The process begins when the warehouse is notified about the arrival of goods in advance. The warehouses then schedules time slots for the incoming trucks, which are usually 30-minute windows (Bartholdi and Hackman, 2019). When the goods arrive, they are unloaded from the truck and moved to the inbound area. The products are usually transported by forklifts or similar, because they typically arrive in larger units such as pallets. After this, the goods are typically registered or scanned into the warehouse management system (WMS). The goods are also inspected to discover any exceptions such as damage or incorrect amounts (Van Den Berg et al., 1998). If there are errors, these are noted and handled. In a typical distribution center, the receiving process usually accounts for about 10 % of the warehouse operating costs (Bartholdi and Hackman, 2019).

Put-away

The second warehousing process is put-away (Van Den Berg et al., 1998). This involves the movement and physical assignment of goods from the inbound area to a storage location (Baruffaldi et al., 2020). The storage location must be determined in advance, which is usually done by implementing a certain storage policy to the WMS. This way the WMS will automatically determine the most optimal storage location based on the storage policy. When a product is put away on its dedicated storage location in the warehouse, it should be scanned and registered in the WMS. Information about where all products are located is useful for constructing efficient picking lists and for determining the optimal order picking routes. It is also useful for guidance to the order pickers. The put-away activity usually accounts for about 15 % of the warehouse operating costs (Bartholdi and Hackman, 2019).

Order picking

The next and most time-consuming warehouse operation is order picking (Van Den Berg et al., 1998). The literature typically states that order picking accounts for 55 % of the total time spent on warehouse operations (Kofler, Beham, S. Wagner and Affenzeller, 2014). It is also the most critical warehouse activity in most distribution centers, because it affects the customer expectations and therefore creates value (Kay, 2015). Order picking includes the process of moving products from their storage location to the outbound area in response to a customer order, in addition to the information processing associated with searching and updating inventory records. The physical material handling is either automatized or performed manually, depending on the size of the warehouse, resources available, and product types and volumes. Order picking of large units such as pallets are often automatized, while the picking of smaller units are often performed manually. Manual order picking is, in general, more time-consuming and labor-intensive than automated order picking.

Order picking is initiated by an outbound order (Van Den Berg et al., 1998). After an order is received by the warehouse, it must be verified that all products in the order are available (Bartholdi and Hackman, 2019). Then, the relevant picking lists must be generated to guide the order pickers. Picking lists include information about the orders such as product types, amounts, and storage locations. These lists can also include the picker route, i.e., the order of what is to be picked and where to transport what. After the picking lists are available, the order pickers travel to the relevant locations and transport the materials from their storage locations to the outbound area. During the order picking process, the warehouse must also produce any necessary documentation for the shipping of the order. The order picking and the shipping must also be scheduled. All activities in this process, except the physical order picking, is usually performed in the WMS. The order picking process is further investigated in Section 3.4.

Checking and Packing

After an order is picked, it has to be checked and packed (Bartholdi and Hackman, 2019). The checking involves inspecting the items in the order to ensure that they are not damaged and that the order is both complete and accurate. The packing involves preparing the goods for shipment to the customer by packing them, labeling them, and sometimes consolidating them into containers. The types of packing depends on the product types and sizes, as well as customer demands. Packing can potentially be labor-intensive, e.g. if each item in the order has to be packed separately and manually.

Shipping

Shipping is the last warehousing process and involves staging the completed orders for shipping along with the assignment of docks to carriers (Bartholdi and Hackman, 2019). In this process the units handled are usually larger than in the order picking process, due to the packing of orders into containers such as pallets and cases. The shipping process is therefore less time-consuming and labor-intensive than the other warehousing activities.

3.3.2 Warehouse Performance

Managing any business in any sector requires measurement of performance because it reveals a lot about the supply chain and identifies challenges and areas for improvement (Bartholdi and Hackman, 2019). For a warehouse to perform well it is important to ensure accuracy, quality, timeliness and cost effectiveness within the warehousing processes, which can be achieved through performance measurement. There are many reasons why performance should be measured in a warehouse, and (Richards and Gwynne, 2014) lists several of them:

- Ensure customer satisfaction.
- Maintain a culture of continuous improvement in the organization.
- Prevent major problems from occurring by identifying potential issues.
- Train employees in the right areas.
- Reward employees where appropriate.

The warehouse performance is commonly measured by using performance indicators, or key performance indicators (KPIs) (Bartholdi and Hackman, 2019). KPIs evaluate the success of either the whole warehouse or particular activities in the warehouse. Such KPIs can be productivity, shipping accuracy, inventory accuracy, dock-to-stock time, warehouse order cycle time, storage density, and level of automation (Frazelle, 2012). In Table (3.1), an overview of the different KPIs for each warehouse operation is shown along with how they affect the total warehouse performance.

As previously stated, order picking is both the most time consuming and expensive warehouse operation. Order picking is therefore the warehouse activity that has the largest impact on the warehouse performance (Staudt et al., 2015). Thus, order picking should be an important focus area in warehouse performance measurement.

3.3.3 Warehouse Management Systems (WMS)

Warehouses are often complex spanning over large areas containing hundreds of thousands of SKUs with many workers and incoming customer orders (Van Den Berg et al., 1998). In order to manage this it is common to implement a WMS. A WMS is a complex software package which helps coordinate everything in the warehouse, i.e., workforce, inventory, storage locations and customer orders (Bartholdi and Hackman, 2019). A WMS usually contains information

	Financial	**Productivity**	**Utilization**	**Quality**	**Cycle time**
Receiving	Receiving cost per line	Receipts per man-hour	% dock door utilization	% receipts processed accurately	Receipt processing time per receipt
Put-away	Put-away cost per line	Put-aways per man-hour	% utilization of put-away labor and equipment	% perfect put-aways	Put-aways cycle time (per put-away)
Storage	Storage space cost per item	Inventory per square root	% locations and cube occupied	% locations without inventory discrepancies	Inventory days on hand
Order picking	Picking cost per order line	Order lines picked per man-hour	% utilization of picking labor and equipment	% perfect picking lines	Order picking cycle time (per order)
Shipping	Shipping cost per customer order	Orders prepared for shipment per man-hour	% utilization of shipping docks	% perfect shipments	Warehouse order cycle time

Table 3.1: Warehouse key performance indicators (KPIs) adapted from (Frazelle, 2012).

about every item in the warehouse, such as how it is packed and at what location it is stored. In addition, the customer orders are received and the picking lists are generated and organized in the WMS. The WMS is connected to the warehouse operations with Auto Identification Data Capture Technology, such as bar-code scanning and radio-frequency identification (RFID), monitoring the flow of material in the warehouse. This data is captured in real-time by the WMS and utilized to coordinate operations and create useful reports on the status of the inventory (Frazelle, 2012). Data from WMS can also be useful for invoicing and payments as it records all incoming and outgoing goods from the warehouse (Bartholdi and Hackman, 2019). Stock locator systems are also a major asset provided by the WMS, because it allows tracking of all storage locations, including forks of a forklift.

The literature distinguishes between the following three WMS types (Bartholdi and Hackman, 2019):

- **Basic WMS:** A WMS that only includes simple information about the warehouse, which is mostly focused on the throughput in the warehouse. It also provide storage control and location as well as storing and picking instructions for the warehouse operators.
- **Advanced WMS:** This WMS has all the features from the basic WMS. Furthermore, the advanced WMS provides tools to plan resources and operations, and synchronize these to include functionalities such as capacity analysis.
- **Complex WMS:** This WMS has all the features of the advanced WMS. In addition, it includes functionalities, such as transportation and dock door planning, which can be useful for optimizing the warehouse operations further.

Activity	% of order picking time
Traveling	55 %
Searching	15 %
Extracting	10 %
Paperwork and other	20 %

Table 3.2: The different activities in the order picking process and their usual time-consumption.

3.4 Order Picking

As previously stated, order picking is the most time-consuming warehouse operation accounting for about 55 % of the total time spent on warehouse operations (Kofler, Beham, S. Wagner and Affenzeller, 2014). It has also been identified as the most labor-intensive and costly warehouse activity (R. d. Koster et al., 2007). A low performance of the order picking process can therefore lead to unsatisfactory service and high operational costs, not only for the warehouse, but for the entire supply chain. Additionally, recent trends in manufacturing and distribution have made the order picking design and management even more complex and important. For all these reasons, order picking is now considered as the highest-priority area for productivity improvements by warehousing professionals.

(Bartholdi and Hackman, 2019) divides the order picking process into the four activities shown in Table 3.2: traveling, searching, extracting, and paperwork etc. As shown, traveling is the most time-consuming part of order picking. It also comprises the greatest part of the expense related to order picking, which itself is the most expensive warehouse operation (Tajima et al., 2020). Therefore, it is important to reduce the amount of unproductive time in the order picking process, and much effort should be invested in order to achieve this.

It is common to designate a storage area reserved for carton picking, because material handling costs increases for small unit handling sizes. This area is called a forward picking area, and it is located close to the shipping area in order to decrease the travel time. Note that only the goods with the highest demand are assigned to these locations (Kay, 2015).

3.4.1 Picking Strategies

Picking strategies can be split into the following three categories (Richards and Gwynne, 2014):

1. **Picker to goods:** Involves manual picking of goods where the picker moves to the goods. This is the most common picking strategy as the majority of warehouses today continue to operate manually. This method is divided into several categories:

    - *Pick to order:* Also known as individual order pick, or discreet order pick, and is the most common method of picking. Involves the picker taking one order or parts of an order, then traveling through the warehouse either by walking or, e.g., using a forklift, and collecting items until the assignment is completed.
    - *Cluster picking:* In this method, the picker takes a number of orders into the warehouse and picks into individual compartments on their cages from the different orders at the same time. This is a method for reducing the overall travel time.

- *Batch picking:* In batch picking, the picker also picks items for several orders at the same time. Rather than having a cluster of different orders as in cluster picking, the orders are consolidated into one picking list. The picked items are broken down to their constituent orders at a later time.
- *Zone picking:* In this picking strategy, the items are picked from defined zones in the warehouse. Each picker is assigned to a specific zone or zones, and they only pick items within their own zone(s).
- *Wave picking:* In wave picking, different orders are combined and released at specific times during the day. This can be to either associate them with other processes such as vehicle departures, replenishment cycles, and shift cycles, or to balance the workload.

2. **Goods to picker:** The goods are moved to the picker. There are several variations on how such a system can be configured, but it is usually a combination of automated and manual picking. The transportation of goods to the picker is an automated process, while the picking from that point is manual. Goods to picker-strategies allows for many benefits, including travel time minimization, better space utilization and more efficient order processing in general.
3. **Automated picking:** This strategy involves fully automated picking processes. For high-volume item picking operations, automated picking systems can have a high impact on the warehouse performance. There are numerous ways of how an automated picking system can be implemented, and there are many common advantages such as increased space utilization, random storage, improved control, labor savings and higher efficiency.

(Kay, 2015) divides the order picking process into three major levels based on the size of the unit being picked (see Figure 3.3):

- *Pallet picking:* Full pallets of cartons or layers of cartons are retrieved. This is also commonly known as unit-load picking.
- *Case picking:* Full cartons of items are retrieved. Also known as carton picking. If the inner packs of items from cartons are retrieved, it is termed split-case picking.
- *Piece picking:* Individual SKUs are retrieved, also known as broken-case picking.

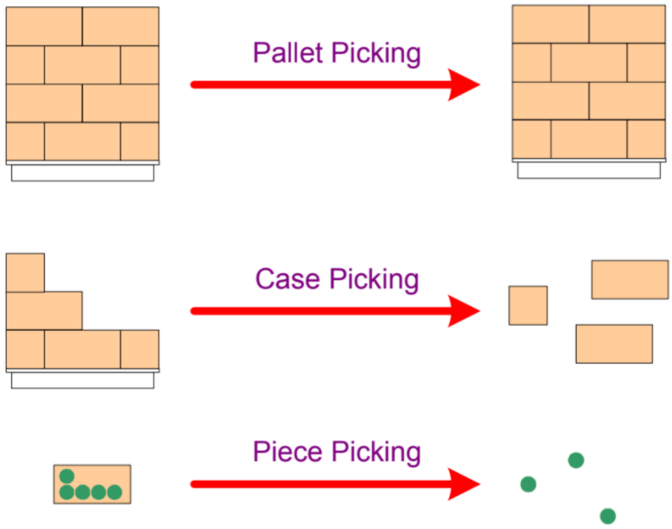


Figure 3.3: Order picking levels based on the size of the unit being picked, adapted from (Kay, 2015).

3.4.2 Picker Routing Policies

Routing methods, or picker routing policies, are methods for deciding the routes of the pickers within the warehouse and finding the optimal sequence to retrieve the goods during order picking (Masae et al., 2020). The goal of these picker routing policies is to minimize the travel distance, and thus, shorten the travel time, which will increase the effectiveness of the order picking process. Picker routing policies are generally solutions to special cases of either the well-known traveling salesman problem (TSP), or to the capacitated vehicle routing problem (CVRP). The idea behind the TSP is finding the shortest possible route between a given number of cities, visiting each city exactly once and returning to the starting city. The standard TSP can be defined mathematically as follows (Bryant, 2000):

Given a weighted graph

$$G = (V, E), \tag{3.1}$$

where the weight c_{ij} on the edge between the nodes i and j is a non-negative value, find the tour of all nodes that has the minimum total cost.

The CVRP, on the other hand, consists of determining the optimal set of routes for a fleet of vehicles to traverse in order to deliver to a given set of customers without exceeding a given capacity constraint (Goos et al., 2007). In the CVRP, each route also begins and ends at the same place, and each customer is visited by exactly one route.

The developed methods for solving the order picker routing problem are usually dedicated to specific warehouse layouts and can therefore often not be generalized. (Masae et al., 2020) identifies three main warehouse layout types: conventional warehouses, non-conventional warehouses, and general warehouses. Conventional warehouses have a rectangular shape with parallel picking aisles that are perpendicular to a certain number of straight cross aisles. If there are two cross aisles on the front and back ends, it is often referred to as a single-block warehouse. If there are more than two cross aisles, the warehouse is called a multi-block warehouse. This thesis will focus on conventional single-block warehouses.

(Masae et al., 2020) divides the existing picker routing policies into three categories: exact algorithms, heuristics and meta-heuristics. These are further described as follows:

Exact Algorithms

Exact algorithms will always find an optimal solution, i.e., the shortest route to travel in an order picker routing problem. The most common algorithm in this category is a version of the classical TSP proposed by Ratliff and Rosenthal in 1983 (hereafter referred to as RR). The RR algorithm has a time complexity linear to the number of aisles and is focused on a conventional single block warehouse. In the algorithm, the picking tour begins and ends at the same place, and the items are picked according to the pick-by-order principle by a single picker. The problem the RR algorithm solves can be mathematically defined as follows:

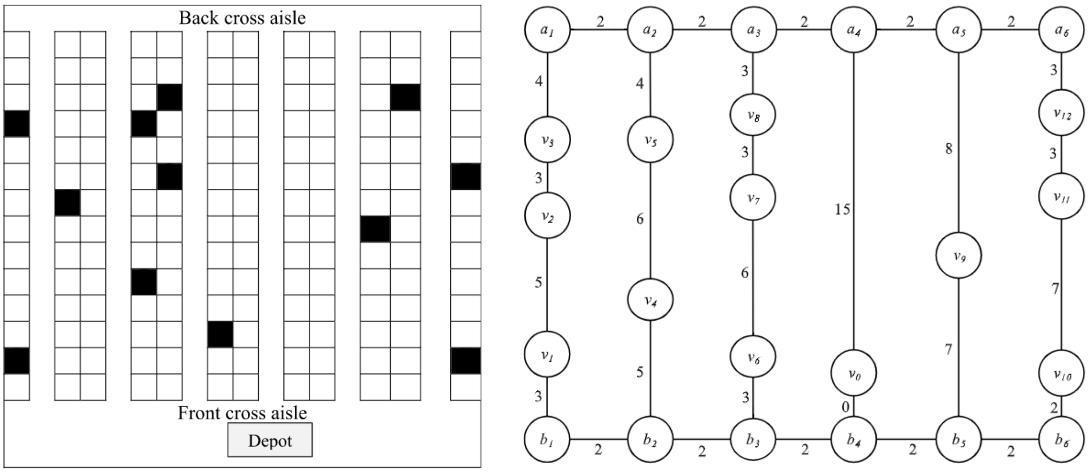
Consider a customer order containing m items to be picked in a conventional warehouse with n aisles. First, define a graph representation G of the warehouse. The vertices $v_i, i = 1, 2, ..., m$, represent the locations of the requested items, and the vertex v_0 denotes the depot where the order picker receives a picking list and drops off picked items (I/O area). The vertices a_j and $b_j, j = 1, 2, ..., n$ are the rear and front ends of each aisle. Then, connect any two vertices in G that correspond to adjacent locations of requested items by parallel edges and add a weight to each edge corresponding to the distance between the vertices connected by the edge. Since any order picking tour of G can be considered as a tour subgraph of G, the objective is to find an order picking tour subgraph of G with minimum length. Figure 3.4a shows an example of a warehouse layout with a single block, and Figure 3.4b contains a graph representation of the warehouse layout example.

In the literature, several variations and extensions of the RR algorithm were identified, most of them for conventional warehouses. As the RR algorithm lacks flexibility and is bound by several constraints, it has frequently been modified in the past.

Heuristics

The types of algorithms called heuristics are problem-dependent and built according to its specifications. In most cases, the results are not optimal. Heuristics are the most common type of picker routing algorithms and there exist several different types. The most common algorithm in this category is called the S-shape heuristic (also known as the traversal method). Here, the order picker begins in the first aisle containing the requested items and traverses that aisle completely while picking the items. Then, the order picker moves to the next aisle containing items from the picking list and traverses it completely. The picker continues in this manner until all items have been retrieved. This method does not always provide the most optimal route, but it has still been widely used because it is simple to implement and understand by order pickers.

Other types of common heuristics include the midpoint, largest gap, return, and composite



(a) Layout of a conventional warehouse with a single block. The black squares shows the picking locations in an example order.

(b) Graph representation G of the example layout in figure (a), where $m = 12$ and $n = 6$.

Figure 3.4: An example of a warehouse layout and a graph representation of it, adapted from (Masae et al., 2020, adapted from Ratliff and Rosenthal, 1983).

methods. In the midpoint method, the warehouse is divided in two equal halves, called the front and the back parts. The aisles in the front part is traversed and picked from first by the order picker, then all the aisles in the back part. The largest gap method also involves dividing the warehouse in two halves, but the largest gap between two requested items is used for defining the front and back parts. In the return method, the order picker enters each aisle that contains at least one requested item from the front end and picks all requested items. When the last item is retrieved, the picker returns to the front of the aisle and continues to the next aisle. The composite method is a combination of the S-shape heuristic and the return method.

Meta-Heuristics

Meta-heuristics are also problem-dependent algorithms, but they are more high-level than heuristics. These algorithms provide a set of guidelines or strategies to find an approximate solution for the order picker routing problem. Meta-heuristics have mostly been used for solving complex order picking problems and combinations of multiple order picking problems. For instance, there have been proposed algorithms solving both the order batching problem and the picker routing problem combined.

3.4.3 Travel Time Estimation

The travel time for an order picking process is defined as the time it takes to travel within the warehouse for different order picking scenarios (Chew and Tang, 1999). An important factor in order picking is, as previously stated, to minimize the travel time. This can be achieved through choosing the most appropriate picker routing policy. Estimating the travel time for different picker routing policies can therefore be used for evaluating their performance.

If a picker routing policy is applied, the average throughput time of a random order can be estimated, because the travel distances, and thus travel times, are known. A method for estimating the travel time in a situation with a random storage policy and a S-shape picker routing algorithm is proposed by (Le-Duc and R. M. d. Koster, 2007). This method finds the optimal batch size for order picking, and provides high accuracy. (Pan et al., 2014) proposes another method that involves travel time estimation in situations with class based storage policies for various routing policies. Whilst most previous studies on warehouse configurations and operations only investigate single-level storage rack systems, this study examines a high-level picker-to-part system.

3.5 Storage Location Assignment Problem (SLAP)

In a warehouse, order-picking has a significant influence on the efficiency of the supply chain, because it is the most time- and labor-consuming warehouse operation (Zhang et al., 2019). In order to optimize the supply chain, it is therefore important to improve the effectiveness of this operation. This is done by achieving the shortest possible order throughput time, i.e. the total amount of time used by an order picker to pick an order, and is one of the major goals for order picking systems in warehouses (Yu and De Koster, 2010). The volume of products, the uncertainty in customer demand and frequent customer service response, makes order picking a complex operation. Therefore, optimizing this operation often requires complex decisions and methods (Zhang et al., 2019). The storage location assignment problem (SLAP) is one of the main operational decisions that have to be made to improve the order-picking efficiency (Reyes et al., 2019). The SLAP is concerned with the allocation of goods to different storage locations inside the warehouse and has the following formal definition (Gu et al., 2007):

Given:

1. *Information about the storage area, including its physical configurations and the storage layout.*
2. *Information about the storage locations, including their availability and physical dimensions.*
3. *Information about the goods to be stored, including their physical dimensions, volumes, demand and arrival and departure times.*

Determine the physical locations in the warehouse where the arriving goods will be stored.

(Gu et al., 2007) presents the following two main decision variables for the storage assignment process:

- Warehouse storage efficiency
- Warehouse access efficiency

Warehouse storage efficiency concerns the storage capacity utilization, and it is achieved through having a high fraction of storage locations utilized at any time. It is a waste to have unused storage locations, thus this should be avoided. Warehouse access efficiency concerns the material handling resources used in the insertion and extraction of goods during the put-away and order picking processes. Effective management of resources is crucial in order to minimize costs and increase performance. Thus, according to (Gu et al., 2007), the SLAP should have the following goals:

- Improvement of space utilization
- Reduction of material handling costs

3.5.1 Storage Policies

The methods for solving the SLAP are called storage policies (Petersen, 1999). Today, there exists multiple storage policies, ranging from basic to rather complex methods. Which criteria to apply in the storage policy depends on the type of warehouse system. The storage policies can be divided into three main categories: dedicated storage, random storage, and class-based storage. The categories are described below along with their different criteria for deciding the storage locations. An overview of the storage policies is depicted in Figure 3.5.

Dedicated storage

This category involves storage policies where each SKU has a predetermined storage location assigned to it (Kay, 2015). All the assigned locations are fixed and permanent for each SKU. This storage policy is sometimes referred to as fixed slot storage. The storage locations can be based on different criteria. The most common criteria in the literature for deciding the storage locations with a dedicated storage policy are described below:

- *Part number:* Assigning the storage locations based on their part/product numbers. This is probably the earliest applied storage policy, because before having access to information systems and tracking of items, the pickers could find different SKUs by following the sequence of part numbers (Bahrami et al., 2019). However, this is not a common decision criterion today.
- *Turnover:* One of the most popular criterion today is based on the turnover or demand of the products (Gu et al., 2007). This is measured as the number of storage/retrieval operations per unit time per product type. In cases where the turnover is used as a storage policy criterion, the products are ranked by decreasing popularity and the most desirable SKUs are assigned the most desirable locations.
- *Cube-per-order-index (COI)*: The COI is defined as the ratio of the maximum allocated storage space to the number of storage/retrieval operations per unit time (Bahrami et al., 2019). The products with lower COI are placed on more convenient locations, and products with higher COI are located in less convenient locations, i.e., further away from the I/O area.
- *Duration-of-stay (DOS):* This criterion is based on the duration of which the products will stay at the warehouse (Kay, 2015). The SKUs will be assigned close to the I/O area if the DOS is short, and further away if the duration is long, in order to optimize the efficiency of the order picking process.

- *Correlation:* Correlated storage (or family-grouping) involves placing similar items close to each other in the warehouse (Bahrami et al., 2019). This criterion is more commonly applied in warehouses containing raw materials, and can be complex to utilize in distribution warehouses.
- *Maximum inventory level:* The maximum inventory is defined as the maximum warehouse space allocated to a product class (Gu et al., 2007). In cases where maximum inventory is applied as a storage policy criterion, the product classes with the lowest maximum inventory are allocated to the most desirable locations.

Randomized storage

Randomized storage concerns storage policies where each SKU is assigned to any open and available storage location (Kay, 2015). This is a simple procedure because the only information needed to implement a randomized storage policy is if the storage locations are available or not. According to (Gu et al., 2007), the four most common randomized storage policies are random location assignment, closest open location, farthest open location, and longest open location. These policies and their criteria are described below:

- *Random location assignment:* Random assignment involves placing the SKUs on a randomly selected slot from all available open slots (Kay, 2015).
- *Closest open location:* The closest open location (COL) storage policy involves placing the SKUs in the open storage locations closest to the inbound area (Kay, 2015). Thus, the locations near the I/O area are filled up quickly and the available spots are farther away.
- *Farthest open location:* This policy the opposite of the COL policy (Kay, 2015). Here, SKUs are assigned to the most remote free positions from the I/O area.
- *Longest open location:* Longest open location involves assigning SKUs to storage locations based on the amount of time the locations have been open (Bahrami et al., 2019).

Class-based storage

The third common storage policy category is called class-based storage. This is a combination of dedicated storage and randomized storage (Kay, 2015). Here, each SKU is assigned to one of several different storage classes, based on an appropriate criteria such as volume or demand. Within the classes, randomized storage can be used while dedicated storage is often used between the classes. This implies that dedicated and randomized storage can be seen as extreme cases of class-based storage: dedicated storage considers a situation with one class for each product, and randomized storage considers a situation with only one class in total (Bahrami et al., 2019).

A widely used type of class-based storage is called ABC inventory classification (Teunter et al., 2009). This is a storage policy consisting of three classes named A, B, and C. Among warehouses, ABC classification is a popular storage policy due to its simple implementation, manageable maintenance, and ability to handle product mix and variations (Bahrami et al., 2019). The main purpose of the ABC classification system (and class-based storage policies in general) is to simplify the task of inventory management by handling stock control methods and service levels for each class instead of for each SKU (Teunter et al., 2009). The system is often based on the Pareto analysis, which is a statistical technique for prioritizing a small number of actions that produce the best overall benefit. This is based on the Pareto principle, which states that 80 % of outcomes are generated by 20 % of causes (Bartholdi and Hackman, 2019). Thus, the class A usually contain a small number of products with high demands, and the class C a larger number of products but with low demands.

The criteria for the classes in an ABC classification system can vary, but most commonly it is classified by decreasing demand value (Teunter et al., 2009). This implies that the A class will contain the products with the highest demand, and class C the products with lowest demand. The most common criterion for the classification is demand value, the annual dollar volume (price multiplied by projected volume), followed by demand volume. Using only a single criterion for the classification has the advantage of simplicity.

The ABC system can also be classified based on multiple criteria, such as the certainty of supply, cost of review and replenishment, design and manufacturing process technology and sustainability (Teunter et al., 2009). This is a more complex approach, and several different methods and algorithms have been proposed in the literature. (Kheybari et al., 2019) presents such a multi-criteria classification system. The model was made by calculating the value and relative importance of each item in the model by using Shannon's entropy, a method for weighting different criteria. The items in the model were then ranked by using TOPSIS, a widely used method in multi-attribute decision making for ranking m alternatives according to n criteria. Finally, goal programming were used for clustering the items into the three classes A, B and C.

Another method for multi-criteria ABC classification is proposed by (Zhou et al., 2020). The method involves using a broad set of features as criteria and using a K-means clustering algorithm for classification of items. In addition to using common criteria such as demand, turnover, value and sales volume, (Zhou et al., 2020) suggests analyzing the habits of the consumers. This way, additional attributes can be added to the model, and the results can be a more accurate classification and an improvement of the traditional ABC system.

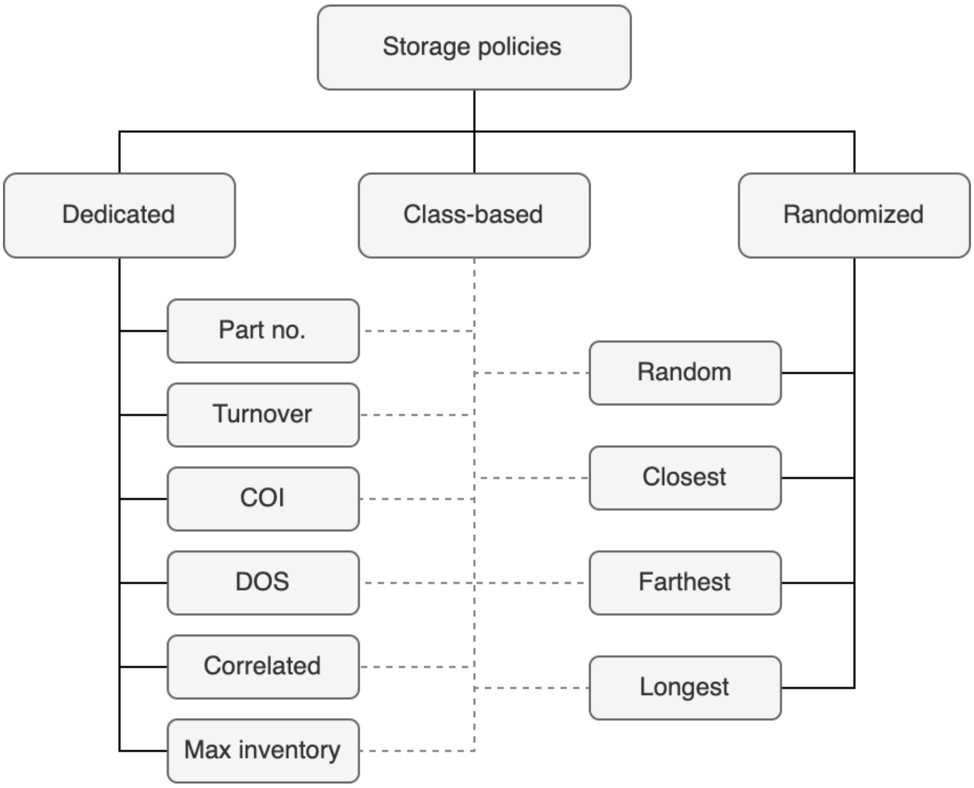


Figure 3.5: Storage policies, adapted from (Bahrami et al., 2019).

3.5.2 Dynamic Storage Policies

The SLAP is a well-established research topic that has been studied for more than 50 years (Kofler, 2014). Still, most publications focus on static storage policies which involves long-term planning in inventory control with fixed storage locations (Gu et al., 2007). This may be an inefficient, misleading and non-optimal method for solving the SLAP (Li et al., 2016). A possible solution is to apply dynamic storage policies as a solution to the SLAP. A dynamic storage policy entails that the SKUs are not assigned permanent storage locations, but have dynamically updated storage locations. The goal of a dynamic storage policy is to optimize the effectiveness of the warehouse by strategically changing the storage locations based on volume and demand. The storage locations can be updated for only the incoming goods, for the goods already stored in the warehouse, or both. The physical movement of goods already stored in the warehouse is called reshuffling, and is described more thoroughly in the next chapter.

It is important to note that implementing a dynamic storage policy can lead to several challenges. Firstly, it is both time- and resource-consuming to physically update the storage locations and relocate the goods (Kofler, 2014). Secondly, the performance gains of the dynamic storage policy must be grater than the cost of relocation of goods. Thirdly, choosing which dynamic storage policy to implement can be challenging as there are many factors, such as demand patterns, the size of the warehouse, the types of products and the available resources, that influence this decision. The core decisions that must be made when applying a dynamic storage policy are which items should be relocated, where to move them, when the movements should be performed and who will move them. Finally, with a static storage policy it is acceptable to have the most desirable storage locations filled up, whilst in a dynamic storage policy this can limit the placement of incoming goods with high turnover rates. For example, if all the desirable storage locations are filled up, popular items may have to be placed in less desirable areas.

A way of implementing a dynamic storage policy is by using dynamic classifications to dynamically change the SKUs' classification in class-based storage based on the fluctuating nature of demand patterns. (Li et al., 2016) introduces a dynamic storage mechanism based on the ABC classification system for a real-life warehouse with a rectangular-shaped configuration and single-layer dimension. Here, the SKUs are classified upon arrival based on mutual affinity, the traditional ABC classification and the relative importance of the SKUs, such as the frequency of ordering. By mutual affinity, the author means that the SKUs with high/low affinity are assigned storage locations close to/far away from each other. The classifications are updated dynamically based on the above-mentioned factors, with the goal of optimizing the material flow and minimizing the throughput time of the orders. Several methods for solving this storage optimization problem are presented in the paper, both dynamic and analytic.

3.5.3 Information Availability in SLAP

Deciding which storage policy to apply in a warehouse can be challenging. (Gu et al., 2007) presents a comprehensive review of this decision process, where the decisions are described in a taxonomy based on the information the warehouse has available. The review examined scientific papers written on the topic before 2006. The available information on receiving and shipping are mapped into the three scenarios described below. The hierarchy of the different information availability scenarios is illustrated in Figure 3.6.

- **No information:** The planner only has prior knowledge on the warehouse layout. Incoming shipments and their contents are not known until they arrive at the warehouse inbound area. In this scenario, the demand is unknown and there is no knowledge basis to apply when determining a storage policy. Only the simplest storage policies are relevant, i.e. closest open location, random location, farthest open location or longest open location (Goetschalckx and Ratliff, 1990).
- **Product information:** The planner has some statistical knowledge of incoming and outgoing shipments. In this scenario, more detailed methods based on product information such as size and usage rate can be applied (Goetschalckx and Ratliff, 1990). In addition, historical data can be studied to retrieve picking frequency, demand, delivery quantities and other general data (Kofler, 2014. This information can then be used to divide SKUs into classes (Gu et al., 2007, Goetschalckx and Ratliff, 1990). This scenario is the most common amount of information availability for warehouses.
- **Item information:** The planner has perfect, or near-perfect, knowledge of the incoming and outgoing shipments. That is, the planner has all the information of the incoming shipments' contents and the order lists of the outgoing shipments. In this scenario, detailed planning of the warehouse operations is possible. For example, the planner can place the item with the DOS to the storage location with the shortest travel distance (Gu et al., 2007, Goetschalckx and Ratliff, 1990).

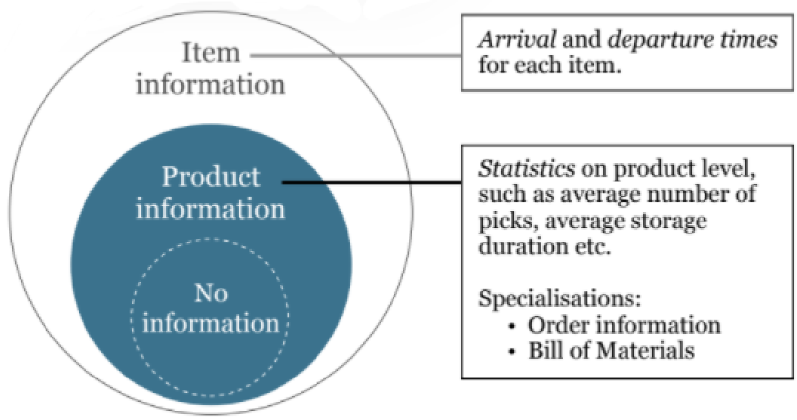


Figure 3.6: Hierarchy of SLAP models, adapted from (Kofler, 2014).

According to (Gu et al., 2007) the static SLAP is the most studied version. In static SLAP, it is assumed that that the material flow is both known and consistent over the planning horizon. However, demand and material flow is often unknown and fluctuating (Ang et al., 2012). Thus, more research should be conducted on non-static SLAP.

3.6 Warehouse Reshuffling

There are several ways to define the concept of reshuffling. (Pazour and Carlo, 2015) describes warehouse reshuffling as a reorganization strategy that consists of repositioning items by moving them sequentially. (L. Chen et al., 2011) uses the term relocation for reshuffling, and defines it as the movement of an item from one storage location to another storage location. In this study, reshuffling is the process of changing from an initial storage assignment location to a new storage assignment location. Note that the concept of reshuffling can be described by several terms, and in this study, reshuffling is applied.

Reshuffling reduces the expected warehouse costs of normal operations at the expense of the costs of the reshuffling (Pazour and Carlo, 2015). If reshuffling is to be beneficial to the warehouse, the savings caused by reshuffling must be greater than the cost of the reshuffling activities. In manually operated warehouses the primary reshuffling cost is labor, and in automated warehouses the primary reshuffling cost is electricity. To minimize reshuffling costs in either type of warehouse, the total travel time associated with the reshuffling process should be minimized. On average, an 8 % to 15 % improvement in picking and replenishment labor is common when reshuffling is applied in a manually warehouse with many SKUs (Trebilcock, 2011). These savings are the result of the reduced labor allowing the warehouse to schedule fewer workers.

Several decisions must be made if goods are to be reshuffled. The warehouse has to select which items are to be reshuffled, as well as their destinations of relocation (L. Chen et al., 2011). There are a number of criteria that can be used when making these decisions. (Muralidharan et al., 2007) suggest reshuffling high demand items nearer the I/O area. (Jaikumar and Solomon, 2007) recommends only reshuffling items that are to be retrieved in order to reduce the order throughput time. (Sadiq et al., 2016) suggests reshuffling items that are more likely to appear in the same order into clusters. (L. Chen et al., 2011) proposes that items that are to be put away or picked during peak periods may be reshuffled closer to the I/O area, thereby reducing the travel time during these periods. (Yu and De Koster, 2010) suggests using a single picking station located close to the I/O area and reshuffling all items included in an order to the picking station prior to the picking operation. The literature shows, that most researchers focus on using the reshuffling activity to move items closer to, or further away from, the I/O area. There is also a high degree of researchers proposing that the items to be reshuffled are based on demand. However, the exact method varies.

The decision of when to reshuffle goods depends on the type of company (Trebilcock, 2011). Examples of when reshuffling is commonly completed, in practice, are: at the launch of a new product, at the end of each season, or on a monthly, weekly, or even daily basis (Pazour and Carlo, 2015). This depends on the volatility of the demand profile. If the demand is only subjected to seasonal changes, the warehouse may only need to reshuffle goods when the season changes. However, if the company is subjected to sudden increases in demand on specific products due to campaigns or new product introduction, as is common for the food industry, the reshuffling may have to be performed for each promotional campaign.

There is limited literature covering the reshuffling of goods in a warehouse. In a paper from 2021, (G. Chen et al., 2021) states that "Little work has been done on the dynamic re-assignment of storage locations during the handling process." The findings in this study indicate that this is especially the case for manually operated warehouses.

3.6.1 Concepts for Reshuffling

The literature revealed two main concepts for reshuffling. The first, re-warehousing, aims to optimize the allocation of all SKUs in the warehouse. The second, healing, aims to have a robust storage policy and occasionally reshuffling a few SKUs to improve the efficiency in the warehouse.

Re-warehousing

Re-warehousing is the study of trying to achieve the optimal allocation of SKUs and the rearranging of the existing warehouse to a large degree (Kofler, Beham, S. Wagner and Affenzeller, 2014). In the real world, this can often hold up personnel and material handling, because it entails the movement of hundreds or thousands of items. The cost-effectiveness of the re-warehousing depends on how quickly demand patterns change (Kofler, 2014). In addition, the savings related to the improved performance during the day-to-day operations caused be the re-warehousing must be greater than the costs of re-warehousing.

Healing

Healing is another approach to dynamic storage policies with reshuffling (Kofler, Beham, S. Wagner, Affenzeller and Achleitner, 2011). It is time- and labor-intensive to constantly have the optimal storage location for all SKUs in a warehouse. A solution is to compromise by having a robust storage assignment and improving it by moving a few SKUs based on demand to decrease the total travel time. In the paper, it was found that moving 60 pallets to a more beneficial warehouse location can reduce the travel distance of pickers by 23 %. The optimal picking distance reduction in this experiment was 60 %, but achieving this will require the relocation of 1400 pallets. In some cases, a good enough solution is all that is needed. This reshuffling approach is called healing. Healing can balance the workload by moving a few pallets a day.

In the healing context, it is very interesting to quantify how "close to optimal" a current SKUs warehouse location is and to determine suitable re-location intervals. This can be measured through a zone-based approach, where the exact location within the zone is not deemed as relevant (Kofler, 2014). This method examines the distance from the actual zone, $\mathrm{Z_{real}(p_i)}$, to the optimal zone, $\mathrm{Z_{opt}(p_i)}$, of a product or SKU, $\mathrm{p_i}$. This distance is called the emergence, ε, of a product or SKU. The emergence is defined as

$$\varepsilon(p_i) = |Z_{opt}(p_i) - Z_{real}(p_i)|^{\alpha(p_i)}, \tag{3.2}$$

where $\alpha(\mathrm{p_i})$ is used to weigh the distance dependent on the pick frequency of a product or product group. If a product is frequently picked, then storing it in the wrong location will have a greater impact than if the product is a slow seller. For frequently picked parts, a value of $\alpha > 1$ is suggested.

There are different ways to measure the performance of both healing and re-warehousing. The appropriate measurement of the results depends on the warehouse and what challenges it faces. One option is to examine the total travel distance, another option is to investigate the system during peak demand (Van Den Berg et al., 1998). For some warehouses, the key issue lies in meeting short time peak demand, which can result in late orders. There are cases where it is beneficial for the warehouse to re-locate products in slack periods and not in peak demand periods.

3.6.2 Automated Warehouses

In an automated warehouse, there are several ways to implement reshuffling of goods. As early as in 1990, (Linn and Wysk, 1990) published a study on AS/RS with a class-based storage policy using idle time for reshuffling items closer to the I/O area. However, this was only conceptual and did not include any details or computations.

(Yu and De Koster, 2010) proposes a more specific solution for a dynamic storage policy with AS/RS for reshuffling of goods. The author refers to the solution as a dynamic storage system (DSS). In the DSS, a single pick station is applied, where the main focus is reducing the travel distance for the order pickers. All customer orders are batched in groups of B orders before they are released to the picking system. All the different product types included in the orders are transported to a picking area by the AS/RS before the release of an order batch. The picking area is located closer to the outbound area of the warehouse than the rest of the goods. The products are continuously reshuffled, in order to meet the products included in the order batches. The DSS has several possible advantages such as a reduction of the throughput time caused by the reduced travel time. The result could be a reduction in the number of required working hours and number of order pickers, which can lead to reduced costs. However, there are challenges related to the DSS. Firstly, it can be difficult to determine the optimal batch size.

Secondly, there may be economical issues related to implementing automated S/R machines, specially for smaller companies. However, with mathematical and simulation modeling, this study is able to demonstrate that dynamic storage with reshuffling can decrease the throughput time and reduce labor costs significantly. The results confirm and quantify the advantage of these methods over conventional picking systems.

(L. Chen et al., 2011) studies an optimization problem on reshuffling of items in a warehouse with a dynamic storage policy. The method involves deciding which items to reshuffle and their new destinations in order to satisfy the required demand during peak periods and handle the fluctuating workloads. A mathematical integer model and two heuristics are proposed for solving the problem. In the paper, it is assumed that the S/R machine is in single command mode, meaning that it performs a single operation (either storage or retrieval) on each trip. Additionally, it is assumed that the storage assignment is determined before applying the reshuffling strategy. The study compares two types of reshuffling policies: one-time reshuffling and separate reshuffling. One-time reshuffling involves performing all the reshuffling operations together in the same interval. Separate reshuffling refers to separating the reshuffling operations and performing them when there is time and open locations to reshuffle items to. The results show that separate reshuffling outperforms one-time reshuffling. The reshuffling is executed during off-peak periods in an attempt for level the workload in the warehouse. However, the success of this is not described as the aim of the study was to minimize the reshuffling time, not investigate the effect of reshuffling on the warehouse performance.

(Carlo and Giraldo, 2012) introduces a new reshuffling strategy called Rearrange-While-Working (RWW). This involves organizing a warehouse by rearranging loads as they are retrieved and re-stored according to a move request list. The objective is to determine the rearrangement sequence that minimizes the total material handling effort measured in distance. It is assumed that an AS/RS retrieves (and stores) loads from (and to) a rack following a predetermined list of move requests that corresponds to a list of orders to be fulfilled. Three cases were investigated in the paper: (1) one empty location with idle equipment; (2) one empty location with RWW; and (3) multiple empty locations with RWW. Several heuristics were tested for all three case studies. The proposed RWW strategy is particularly useful for warehouses with a high throughput. The proposed RWW policy can be used in combination with idle time reshuffling policies. The scope of the study was optimizing the reshuffling process, not comparing the effect of the proposed storage location strategy, RWW, with existing policies.

Another study on dynamic storage reshuffling with automated S/R systems are performed by (G. Chen et al., 2021). The main motivation behind the study is to improve the retrieval operational efficiency in a large automated warehouse by reducing the total crane travel time. In the paper, several different reshuffling methods are investigated and many numerical experiments have been performed. It is assumed that an automated crane moves full pallets to an order picking point. The amount to retrieve is often less that a full pallet load, and normally the rest of the pallet is moved back to its original location. However, the goal of the study is to improve the retrieval operational efficiency by dynamically re-assigning the storage locations of nonempty pallets after each retrieval. Various heuristic methods and dynamic programming methods are tested with different reshuffling policies such as random reshuffling and closest-open reshuffling. The study found that random reshuffling is in general no better than no reshuffling, and that closest-open reshuffling is effective across different rack shapes, crane velocity configurations, and retrieval characteristics. The results can be translated into system throughput time, and shows that closest-open reshuffling improves this.

3.6.3 Manually Operated Warehouses

The existing research regarding reshuffling of goods in manually operated warehouses is very limited. However, the researchers in this study were able to locate one article related to goods reshuffling on manually operated warehouses specifically.

(Pierre et al., 2003) introduces a dynamic version of the ABC storage policy that uses reshuffling. This variant is for a manual order picking warehouse and the classification of items are based on the daily number of order lines. As the classification of items change, the items are reshuffled, if necessary, to the storage area corresponding to their classification. If the reshuffling uphold each storage zone's capacity constraints, the estimated time to perform the reshuffling does not exceed the time capacity. The primary goal of this storage policy is to reduce the average working time per day. This is achieved through an iterative procedure of reviewing and reassigning item classifications. In a simulation using test data from a case study, the results indicate that when the reshuffling time increases, the order picking time decreases and vice versa.

3.7 Summary of the Theoretical Background

The key theoretical findings from this chapter can be summarized as follows:

- Actors in the FMCG industry must be flexible, as the industry is characterized by constant changes and a highly variable demand pattern. The Norwegian food industry can be classified as an actor in the FMCG industry.
- The 3PL sector is experiencing tremendous growth, which means that they must differentiate themselves to stay competitive.
- The most expensive resource in a manually operated warehouse is labor. Order picking is the most time consuming, and thus expensive warehouse operation. Traveling can account for a majority of the time spent on order picking.
- Even though the SLAP is a well established research topic, most solutions focus on static storage policies.
- There are several different storage policies for warehouses. The ABC classification is the most common static storage policy and it can also be applied dynamically.
- Reshuffling is a method that can be used to update the storage locations as the demand changes. For the reshuffling activity to be beneficial for a warehouse, the savings caused by the reshuffling operation must be greater than the cost of the reshuffling operation itself. The main reshuffling cost in a manually operated warehouse is labor.
- The criteria for warehouse reshuffling varies, but most researchers focuses on reshuffling goods closer or further away from the I/O area based on product demand.
- The decision of when to reshuffle goods is dependent on the type of warehouse and its demand patterns.
- Even though the concept of warehouse reshuffling was introduced as early as 1990 the research on the topic is limited, especially for manually operated warehouses.

Chapter 4

Case Study

This case study is focused on the 3PL provider of warehousing services Leman and their largest customer Brynild. This chapter introduces these two companies followed by a detailed description of Leman. Then, the current situation at Leman is analyzed, followed by a reshuffling analysis. Based on these analyses, several proposals for improving the order picking process through reshuffling are given. Finally, the case study is discussed.

4.1 Introduction

4.1.1 The Supply Chain

Leman is a 3PL provider for Brynild Gruppen AS (hereafter referred to as Brynild), offering warehousing services for their products. All Brynild's products are stored at Leman's warehouse department in Vestby. These products consist mostly of end-items, but they also store some raw materials. Leman performs many kinds of warehousing services for Brynild, including handling incoming and outgoing goods, picking of mixed pallets, repacking of goods, wrapping, etc. Brynild is responsible for the sales and distribution of the goods, and the transportation is organized by both Brynild and Brynild's customers. Leman is thus mainly responsible for the warehousing activities. The supply chain of Leman and Brynild and is shown in Figure 4.1.

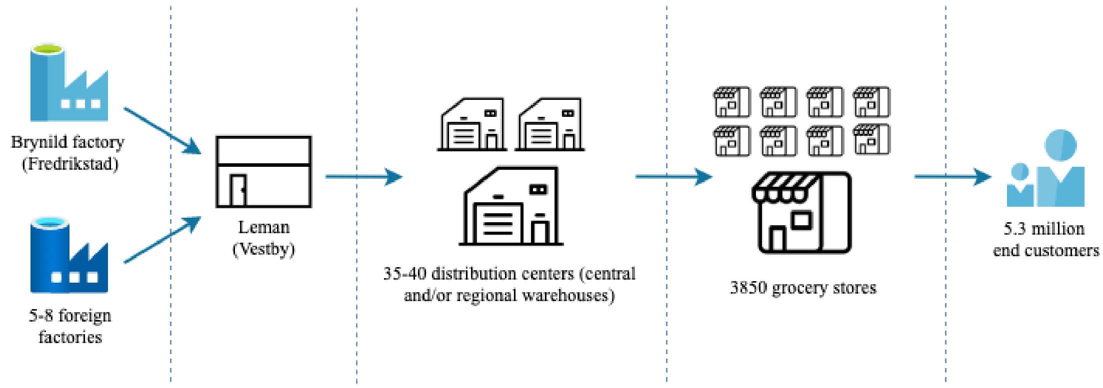


Figure 4.1: A simplified illustration of the supply chain of Leman and Brynild.

4.1.2 Leman

Leman AS is a Danish 3PL provider offering logistics services to companies worldwide, founded in 1900 in Copenhagen. Their services involve different types of transport, warehousing, and other logistics activities. Leman AS is currently located in eight countries with approximately 750 employees in total. The company currently has two Norwegian departments, one in Drammen and one in Vestby. This case study is focused on the department in Vestby, as this is where Brynild's products are stored. Leman's facility in Vestby originated as Dan Cargo AS, a transportation logistics company distributed on two locations: one in Moss and one in Vestby. In 2014, Dan Cargo AS was acquired by Leman and the two locations were merged into one. Leman's facility in Vestby (hereafter referred to as Leman) can be considered as a SME with 25 full-time employees.

Leman performs several activities for their customers, but their core competence is warehouse operations. They also offer logistics services such as transportation and customs clearance. Leman currently has 13 different customers, and Brynild is the largest one. Among the other large customers are Jensen AS, Nutricia AS and Kavli AS. Leman is focusing on forming long-term contracts with their customers and developing mutually beneficial relationships. Therefore, they sign 5-year contracts with all of their clients.

4.1.3 Brynild

Brynild is the largest family-owned confectionery company in Norway. The company has been owned and managed by the Brynildsen family ever since its establishment in 1895. Brynild is a FMCG company that offers confectionery products such as chocolate, confections, hard candy, sweets, nuts, and dried fruits. The company now markets several different brands, including Dent (mints and gum), Brynild (confections), Minde Sjokolade (chocolates), Michael's Farm (nuts), and Den Lille Nøttefabrikken (snacks and nuts). In addition to Brynild's products, they also distribute externally produced items for Beiersdorf AS (Nivea) to the Norwegian market. Brynild's factory is in Fredrikstad, Norway, with a production plant where many of their products are manufactured. Brynild also use several factories outside of Norway.

4.2 Current Situation

In order to fully understand the current situation at the Leman warehouse, the AS-IS situation is described in great detail.

4.2.1 Warehouse Layout

Leman's warehouse in Vestby, where Brynild's products are stored, measures 16,000 m^2. The warehouse holds products for 13 different companies, where Brynild is the largest one. The warehouse is currently separated into three large halls. One hall stores products from the 12 other companies than Brynild in addition to the Beiersdorf products (Nivea) from Brynild, and the second hall consists only of Brynild's own products. The third hall is just finished and the application of it is not fully decided yet.

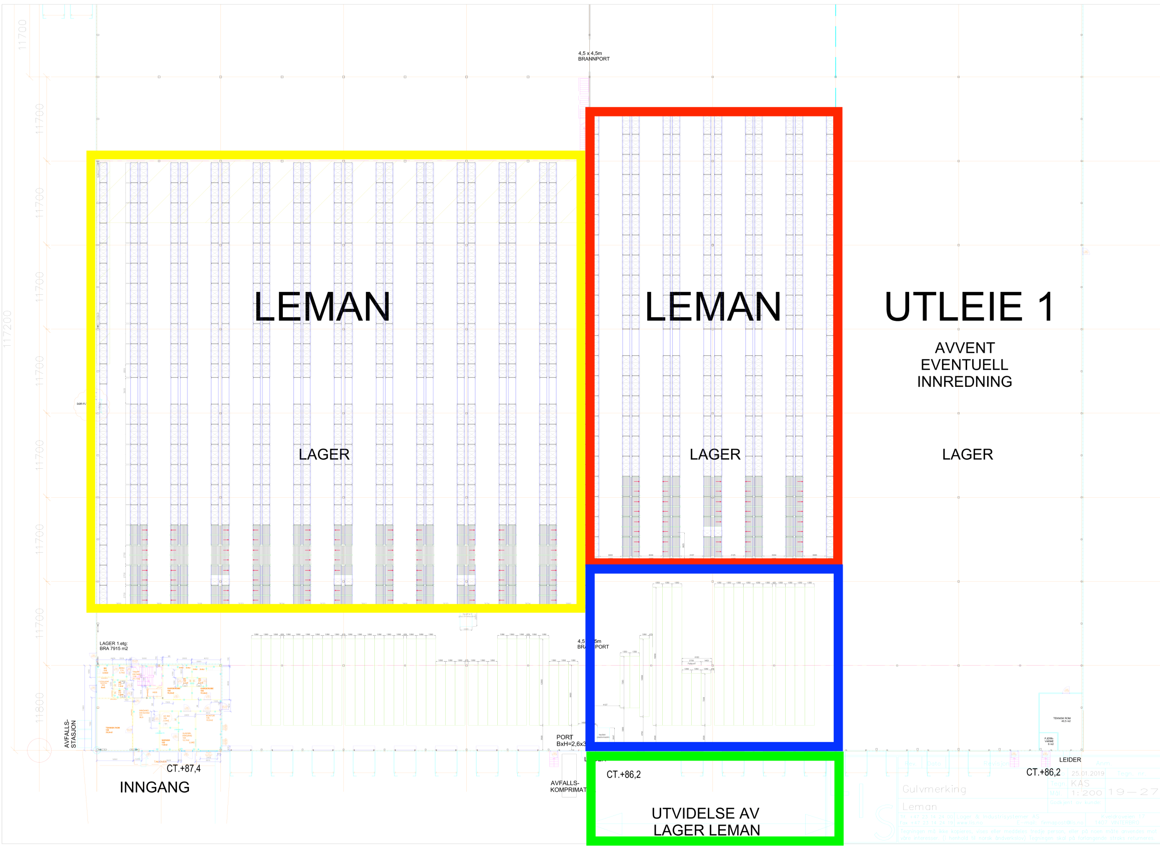


Figure 4.2: An illustration showing the warehouse layout at Leman.

The layout of Leman's warehouse in Vestby is shown in Figure 4.2. The red area is where all Brynild's own products are located, while the yellow area is where the goods from Leman's 12 other customers, in addition to the Nivea products that Brynild has, are located. The green area is where all the goods are delivered and received. The blue area is the I/O area where all the goods are stored after reception or before shipment. At the space called "UTLEIE 1", the new storage hall is located.

The storage hall containing Brynild's products, considered in this study, consists of 8 aisles and 18 racks, illustrated in Figure 4.3. Each rack consists of multiple bays in the horizontal direction and 8 shelves in the vertical direction. The bottom level is used for carton picking while the remaining levels are used for picking full pallets. All the aisles are wide enough for a forklift to operate comfortably and turn without issue. Figure 4.3 also show the I/O area, which can be described as a temporary storage area and work area for goods awaiting put-away, re-packaging and shipping. There is also an area reserved for packing mixed pallets in front of rack 25.

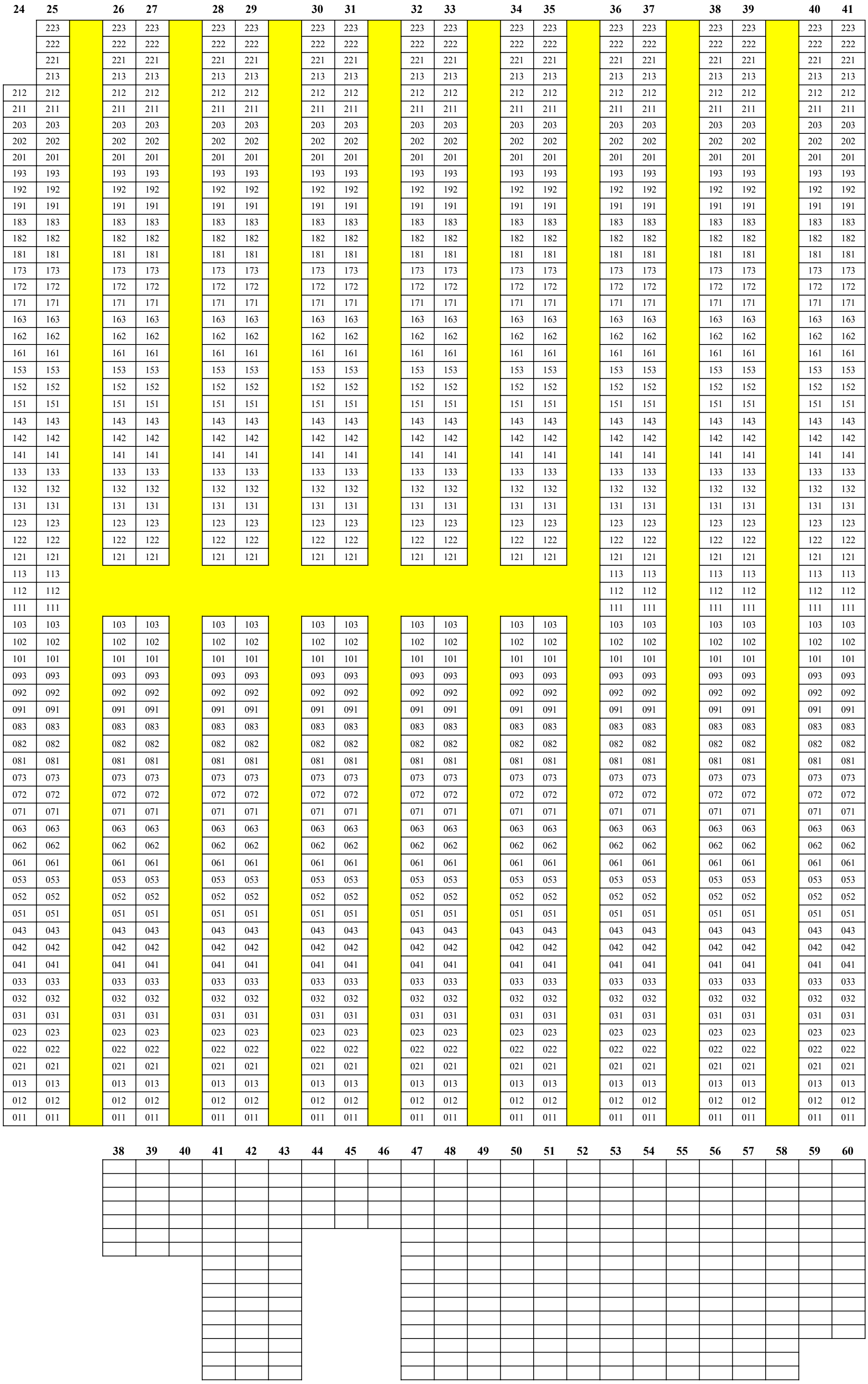


Figure 4.3: The layout of the hall containing all of Brynild's products as seen from above. The racks are numbered from 24 to 41, as shown on top of the layout. The yellow areas shows where the operators can travel at the ground level of the hall. The bottom area in the figure, numbered from 38 to 60, shows the I/O area with its available pallet locations.

All the storage locations in the warehouse are equipped with a unique address and a bar code to ensure that it is traceable in the warehouse. The address describes the rack number, the bay number and the shelf number.

4.2.2 Warehouse Principles

Leman uses an ABC classification system for Brynild's products. The storage area is divided into zones for the different classifications. The A items are stored in the zone closest to the I/O area, while the C items are located the farthest away from the I/O area. The distances are based on both the distances on the floor and the distances in height, as the shelves are tall, and it can be time-consuming to pick pallets from the higher shelves. Additionally, Leman operates with classes D, E, F and G for other materials than Brynild's finished products such as raw materials, packaging materials and promotional materials. Figure 4.4 shows the locations of the classes A, B and C on the ground floor of the storage area (shelf 1), and Figure 4.5 shows the locations of the classes for shelves 2 to 8.

The ABC classification system is based on the picking frequency of the SKUs. The A items are the SKUs with the highest picking frequencies, while the C items are the SKUs with the lowest picking frequencies. Leman's goal is currently to update ABC classifications manually every 14 days, which is the IT manager's responsibility. He updates the classifications based on his knowledge and experience and by looking at historical sales data. Sometimes, the operators indicate that one article number has become a high-runner, and the IT manager checks and updates the classification if necessary.

The way Leman applies the ABC classification method today, no SKU has a fixed position. When the ABC classification is updated, each SKU is assigned to a class. As new goods arrive, the WMS assignes a storage location in the zone corresponding to the class. Thus, the positions of the products changes constantly. The IT manager states that they have discussed having some fixed picking locations for carton picking. This is because there are some products that are included in almost every order and it could be beneficial to locate these in the same area.

The order picking process can be decomposed into storage/retrieval (S/R) cycles. The picking of one full pallet equals one S/R cycle. That is, the S/R cycle starts when the warehouse operator leaves the I/O area to retrieve a full pallet and ends when the operator returns to the I/O area withe the requested pallet. Picking a layer of cartons of a SKU for a mixed pallet can also be viewed as a single S/R cycle. This is because the operator must return to the I/O area after retrieving the requested amount of cartons for that SKU to add a pallet between each carton layer. However, the warehouse operators sometimes stack pallets in arbitrary locations in the storage area to minimize travel distance.

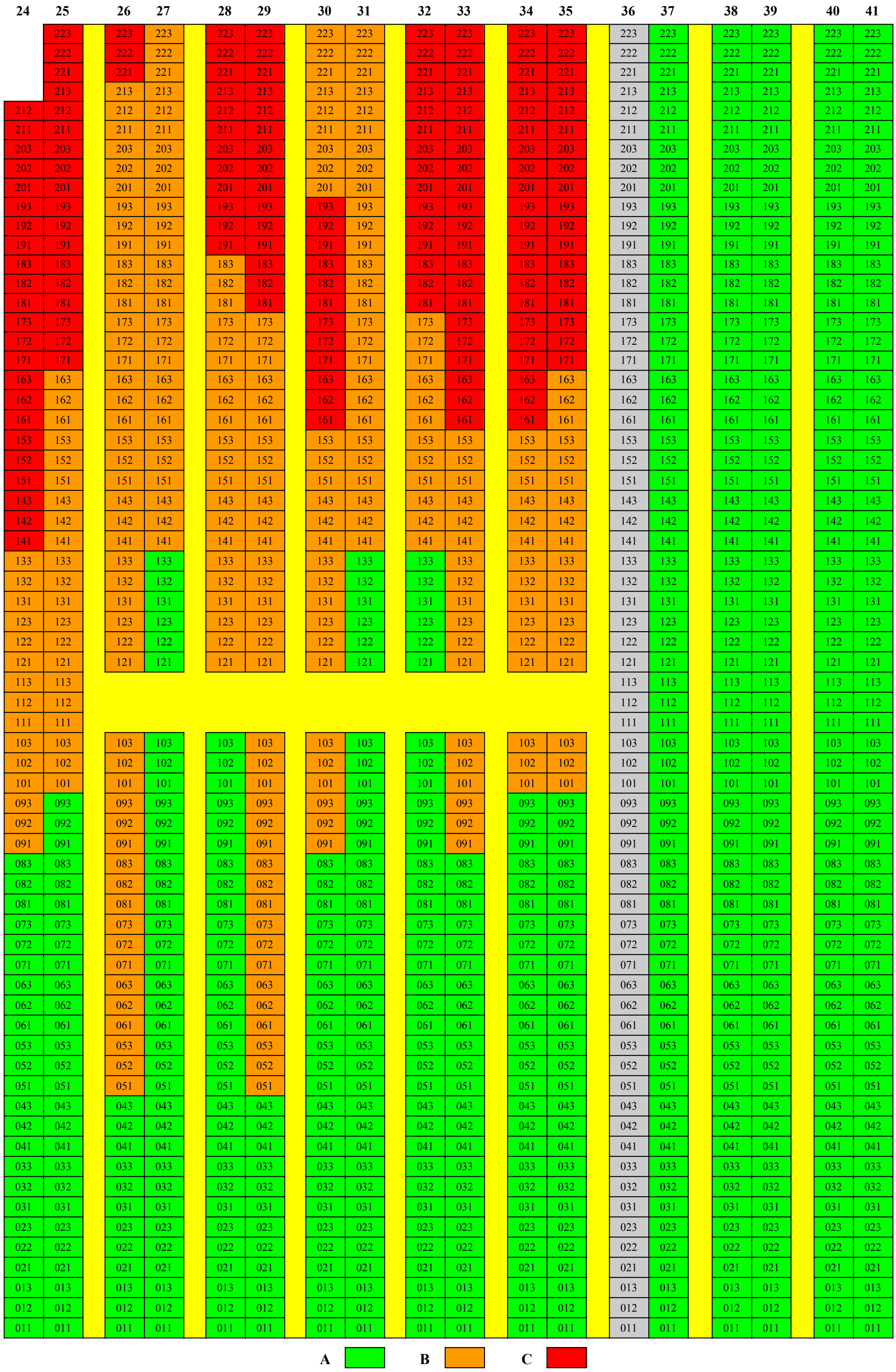


Figure 4.4: An illustration showing the locations of the classes A, B and C on the ground level of the racks in the storage area, as seen from above. The gray areas corresponds to class G and consists of raw materials. The yellow areas shows where the operators can travel.

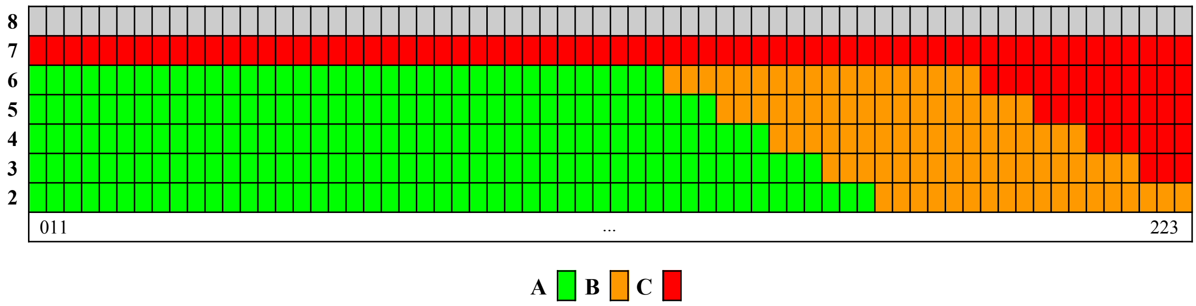


Figure 4.5: An illustration showing the locations of the classes A, B and C on shelves 2 to 8 of the storage area, as seen from the side. The gray areas corresponds to class D.

In addition to the ABC classification, Leman also operates on the first-expired first-out (FEFO) principle. This implies that the SKUs with the earliest expiration date are picked first when picking orders, with a few exceptions. Some of Leman's customers have special demands about minimum durability for their orders. In these cases, the products with the shortest expiration date within the specified limits will be picked first. The FEFO principle is applied to avoid expired SKUs. It also results in that each picking line can only be fulfilled by one production batch, which helps maintain traceability in the supply chain.

Another principle that Leman tries to apply, is placing heavy SKUs in the lower shelves and light SKUs in the higher shelves. According to the IT manager, this is in order to save energy as it requires more battery capacity to place a heavy SKU in the upper levels. However, this is not a strict rule, and if there is no room left in the lower levels a heavy SKU will be placed in the upper levels.

There are currently very few principles in place when it comes to the outbound area. The outbound location for an order is based solely on availability. An outbound location in the designated Brynild storage area is prioritized, but if there are no locations available there, an outbound location in another storage area is chosen. Leman occasionally experiences that the outbound area is completely full. Due to this, the operators are encouraged to stack the outgoing pallets on top of each other to improve space utilization.

There are cases where the warehouse operators overrule the above stated principles. This can happen in situations where:

- A pallet is seen to be unstable, but is assigned to a position of high altitude. Here, some operators choose to place the pallet on a lower shelf in order to avoid the risk of the pallet falling.
- The warehouse operator is putting away two unit loads at the same time. The warehouse operators may ignore the assignment given by the WMS and prioritize storing pallets close to each other in order to minimize travel distance during the put-away operation.
- Discrepancies in the WMS cause the warehouse operators to arrive with a unit load at an already occupied location. The warehouse operators will then place their unit load in another storage location.

4.2.3 Warehouse Operations and Activities

Leman performs several operations for Brynild in their warehouse facility located in Vestby. However, their main function is to handle the inventory for their customers. There are three main activities related to the handling of pallets:

- **Inbound full pallets (IFP):** This activity concerns the handling of the incoming full pallets upon entry. A truckload of pallets arrive approximately 3-4 times a day, with some seasonal variations. Table 4.1 shows the number of inbound pallets for Brynild's products at the Leman warehouse for the period January 2015 to September 2021. Upon arrival, the pallets are unloaded in the I/O area, and the order is registered by an operator in Leman's warehouse management system (WMS). Then, the pallets are automatically assigned different storage locations based on the ABC classification system. The location of each pallet appears on the operator's screen attached to their forklift. The operator then moves all the pallets to their assigned storage locations by using the forklift.
- **Outbound full pallets (OFP):** This activity involves the transportation of full pallets from their storage locations and to the I/O area, i.e., full pallet picking. This is initiated by a customer order, which appears on the operator's screen. The operator then uses a forklift to transport the full pallets listed in the order to the in- and outbound area. The full pallets are not processed and leave the warehouse in the same condition as they were received.
- **Outbound mixed pallets (OMP):** This activity is also initiated by a customer order and concerns the process of assembling pallets of cartons from different pallets/product types, i.e., carton picking. The cartons are picked from the bottom shelf and placed on a new pallet. Some customers also require that the different SKUs are separated by article numbers with a pallet between each layer. When the mixed pallet is full, it is transported to a wrapping station and wrapped in plastic. Then, it is moved to the in- and outbound area. Trucks are used for this activity. This is the most time-consuming activity because it involves a lot of traveling inside the warehouse in addition to the assembling process.

Period	**Number of inbound pallets**
Jan. 2015 - Sep. 2021	362 208
Average per year	53 644
Average per month	4 472
Average per day	233

Table 4.1: Number of inbound pallets of Brynild's products at the Leman warehouse, adapted from Brynild's KPI reports.

In addition to these three main order handling activities, Leman also performs other activities. One activity concerns creating different sales solutions that Brynild sells to specific retailers. These sales solutions consist of store displays made of cardboard that carry a selection of specific SKUs. The repacking of sales solutions is done in Leman's warehouse and is performed partly by Leman and partly by non-profit organizations arranged by Brynild. During the day shift, an operator transports all the required unit loads from their storage locations to Leman's mezzanine by using a forklift. Then, the warehouse manager controls that all the associated cardboards and requested SKUs are placed on the mezzanine. The repacking of sales solutions is then performed after Leman's regular working hours, to avoid interference with the normal activities in the warehouse. After the sales solutions are finished, they are packed back on pallets. The next day, an operator moves the repacked pallets to the I/O area, or to a storage location if the order is scheduled later.

Another operation performed by Leman is restacking SKUs onto new pallets. This operation is done because some of the goods arrive on pallet types that are undesired by the customer. This is a frequent operation due to different customer requirements, according to the operations manager. These requirements are often based on automation at the customer's distribution centers, which leads to them only being able to handle certain types of pallets.

Some of Brynild's SKUs arrive at Leman with a packaging that makes the pallets unable to be stacked on top of each other. In these situations, Leman must set up racks around the pallets in the I/O area. These racks must be set up and removed by hand. The operators must move in and out of their forklifts many times while working with this activity. Thus, these pallets are more time-consuming to handle than stackable pallets. According to the operations manager, this is also a frequent operation.

Number of picking lines		
Period	**Full pallets**	**Mixed pallets**
Jan. 2015 - Sep. 2021	305 146	301 422
Average per year	45 252	44 586
Average per month	3 767	3 721
Average per day	197	194

Table 4.2: Number of picking lines for full pallets and mixed pallets, adapted from Brynild's KPI reports.

Table 4.2 shows the number of picking lines for full pallets and mixed pallets of Brynild's SKUs that are shipped from Leman between January 2015 and September 2021. The ratio for a full pallet and a picking line is one to one, whilst a picking line for a mixed pallet equals the pick of one carton layer. Thus, the ratio between a mixed pallet and a picking line is one to minimum two, depending on the number of SKUs in the carton layer. Table 4.2 shows that the number of picking lines for full pallets and mixed pallets are evenly distributed.

When it comes to the number of cartons per pallet, this only relevant for mixed pallets. This is because shipping a full pallets requires the same workload regardless of the number of cartons it consists of. However, for a mixed pallet the number of cartons will affect the workload and is thus relevant to consider. The data from Brynild's KPI report shows that, on average, 34 cartons were picked per order line for the mixed pallets. The different physical sizes of the cartons for each SKU and the fact that a pallet is required between each SKU for mixed pallets makes the number of picking lines per mixed pallet highly variable.

4.2.4 Products and Equipment

Products

Brynild has several different products. The products are divided in the different brands Den Lille Nøttefabrikken (snacks and nuts), Minde Sjokolade (chocolate), Michael's Farm (nuts), Dent (mints and gum), and Brynild (confections). Additionally, Brynild also distribute externally produced items for Beiersdorf AS (Nivea) to the Norwegian market. In this case study, the Nivea products are not considered.

Pallets

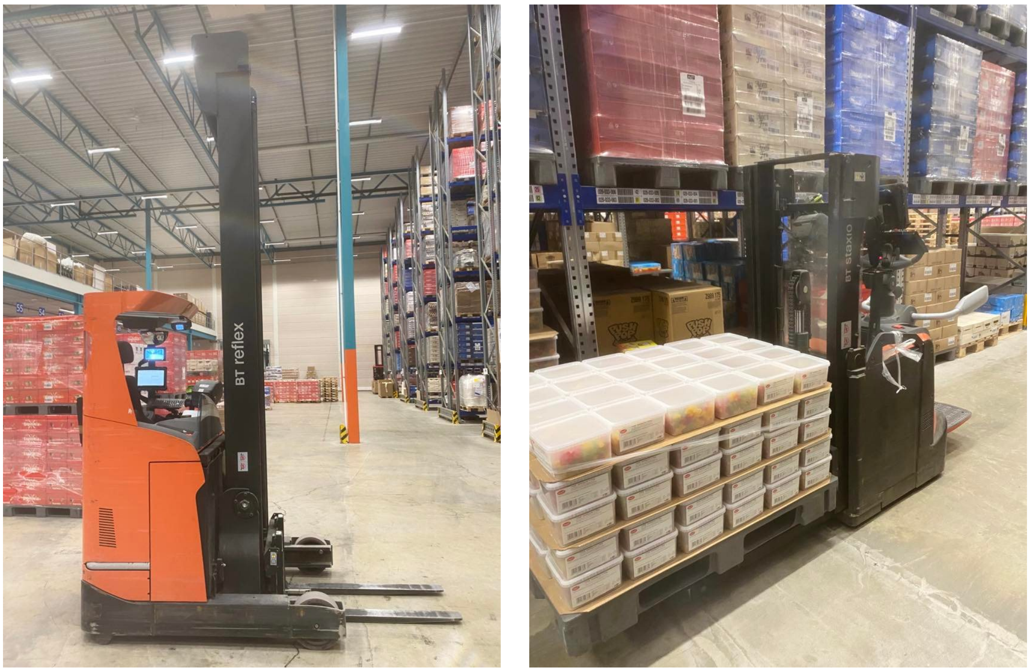
Leman handles two different pallet types: full pallets and mixed pallets. The full pallets contains only one product type, while the mixed pallets consist of several different types, usually with a pallet between each product layer. Examples of the two pallet types are shown in Figure 4.6. The size of the pallets Leman store varies. Most of the inbound pallets have a height between 120 cm and 130 cm, which is the standard size. There are some special products that have a pallet height of 160 cm to 180 cm, these pallets cannot be stored in every storage location as they are to tall. The standard width of the pallets is 80 cm, but Leman sometimes receives pallets that are wider. If the pallet is wider than the standard 80 cm, the WMS will register this when the pallet is scanned.

(a) A full pallet. (b) A mixed pallet.

Figure 4.6: The two different pallet types.

Trucks

For the order picking process, Leman use two different types of industrial trucks. For picking of full pallets, a forklift of the type reach truck is applied. These forklifts can reach pallets up to approximately 14 meters above the ground, and can therefore pick pallets from the top shelves. Here, the operator sits inside of the truck. For the mixed pallets, a pallet truck is applied. This type of truck can reach the two bottom shelves in the warehouse. Here, the operator stands on the pallet truck, which makes it easier to step on and off the truck. All the trucks at Leman can be used to transport all the different types of pallets. The different truck types are shown in Figure 4.7



(a) Forklift used for full pallets.

(b) Pallet truck used for mixed pallets.

Figure 4.7: The two different truck types.

4.2.5 Product Demand

Product Demand at Brynild

The product demand of Brynild's products is fluctuating and varies from week to week. In addition, the wholesaler continuously expect a high service level with short lead times. As a result, understanding the demand is challenging and there is a high level of uncertainty. Thus, Brynild decomposes their experienced demand into four uncertainty-groups. The four uncertainty-groups are:

- **Campaign demand:** When there is a product campaign, production quantities are determined by Brynild and a retailer four to eight weeks before the campaign starts. Thus, the campaign demand is confirmed four to eight weeks in advance of the campaign.
- **New product introduction:** When a new product is introduced, there is always a high

degree of uncertainty of the future demand. Demand is forecasted through the use of qualitative knowledge and experience.

- **Seasonal demand:** Seasonal demand refers to excess sales of products during certain periods of the year, such as Easter and Christmas. The products can be both seasonal and regular. The demand is forecasted using historical data from from previous seasons, and added to the regular demand. To ensure that the production capacity is sufficient, the volume for each season is determined four months in advance.
- **Regular demand:** Regular demand refers to the sales of products not related to any of the previously mentioned uncertainty-groups. In this case, demand is forcasted based on historical data.

The SKUs can be divided into three main categories, regarding the seasonality:

- All season SKUs with (relatively) stable demand, e.g., nuts and hard candy.
- All season SKUs with seasonal fluctuations in demand, e.g., confectionery and candy.
- SKUs that are only sold in specific seasons, e.g., Easter and Christmas chocolate.

Product Demand at Leman

The information Leman receives from Brynild is limited. Leman receive the production plan of Brynild's factory in Fredrikstad, but not for Brynild's other factories. For Leman, the demand patterns cause the following challenges related to storage location assignment and workload:

- **Campaign demand:** Brynild does not inform Leman of imminent campaigns. Campaigns cause an increase in workload for Leman with spikes in incoming shipments and orders, which is difficult to predict.
- **New product introduction:** Brynild does not inform Leman of new product introductions. As a result, Leman is not made privy to the demand forecasts of the new product made by Brynild. This means that, for new products, Leman has no information to base the storage assignment decision on. Leman handles this by initially classifying new products in class A. The pick frequency of the SKU is then tracked, and the classification of the product is updated as more information becomes available.
- **Seasonal demand:** The only notification Leman receives from Brynild about increased production volumes is the production plan of one of their factories. In addition, the products related to the seasonal demand arrives at the warehouse months before the demand actually increases. Leman often has limited information to base decision-making on. As a result, potentially good storage locations can be occupied by products related to seasonal demand for months before the demand increases.
- **Regular demand:** Brynild does not share their demand forecasts, only their production plan of one factory. Neither does Leman have any forecasting of their own. This makes demand planning challenging, because of short lead times. As a consequence, Leman often finds themselves chasing demand with temporary labor and overtime.

In order to illustrate the volume of the demand, the number of outbound orders for Brynild's products at Leman are shown in Table 4.3. The data describes the periode from January 2015 to September 2021. There are on average 30 outbound orders per day, each with an average of 7.8 order lines. According to Leman, even if future demand in terms of order quantities is known, the form in which the orders arrive is not. Thus, workload planning would still be difficult, since mixed pallet picking requires significantly more labor than full pallet picking.

Period	**Number of outbound orders**
Jan. 2015 - Sep. 2021	46 833
Average per year	6 926
Average per month	578
Average per day	30

Table 4.3: Number of outbound orders for Brynild's products at Leman, adapted from Brynild's KPI reports.

4.2.6 WMS

Leman's WMS system is called Astro and is provided by Consafe Logistics. Astro is used for facilitating the daily activities at Leman such as planning, organization, staffing, directing and warehouse-keeping in general. Information about all the different product types is also stored in Astro. All of the operators working in the warehouse have access to a touch screen on their respective forklifts which are connected to Astro, as shown in Figure 4.8. Here, information about the activities appears. When goods arrive at Leman, an operator scans all the goods with a scanner connected to their truck/pad to register the order. Then, the locations of those goods appear on their screen, and they move the goods to their assigned locations. Orders for outgoing goods also appear on their pads. Here, the operators can click on an order, and then a list of all products in that order shows up. The list includes the products' article numbers, quantities, and locations. When doing these activities, the operators constantly scan the pallets/cartons after moving them, so that their locations are always updated in the WMS.

Information about the ABC classification is also stored in the WMS. The IT manager manually updates the ABC classifications regularly (usually every 14 days). He does this by looking at historical data or using his experience. When a product gets a new classification, Astro will automatically find the best location in this classification area.

Location Search Functionality

The storage location functionality in Astro is initiated by an operator when an incoming unit-load is registered in the WMS. After the registration, Astro will automatically suggest a storage location based on the ABC classification system, the information about the unit-load, and the status of the storage area, such as which locations are available and unavailable. The operator can at any time override the suggested location and select a different location manually instead.

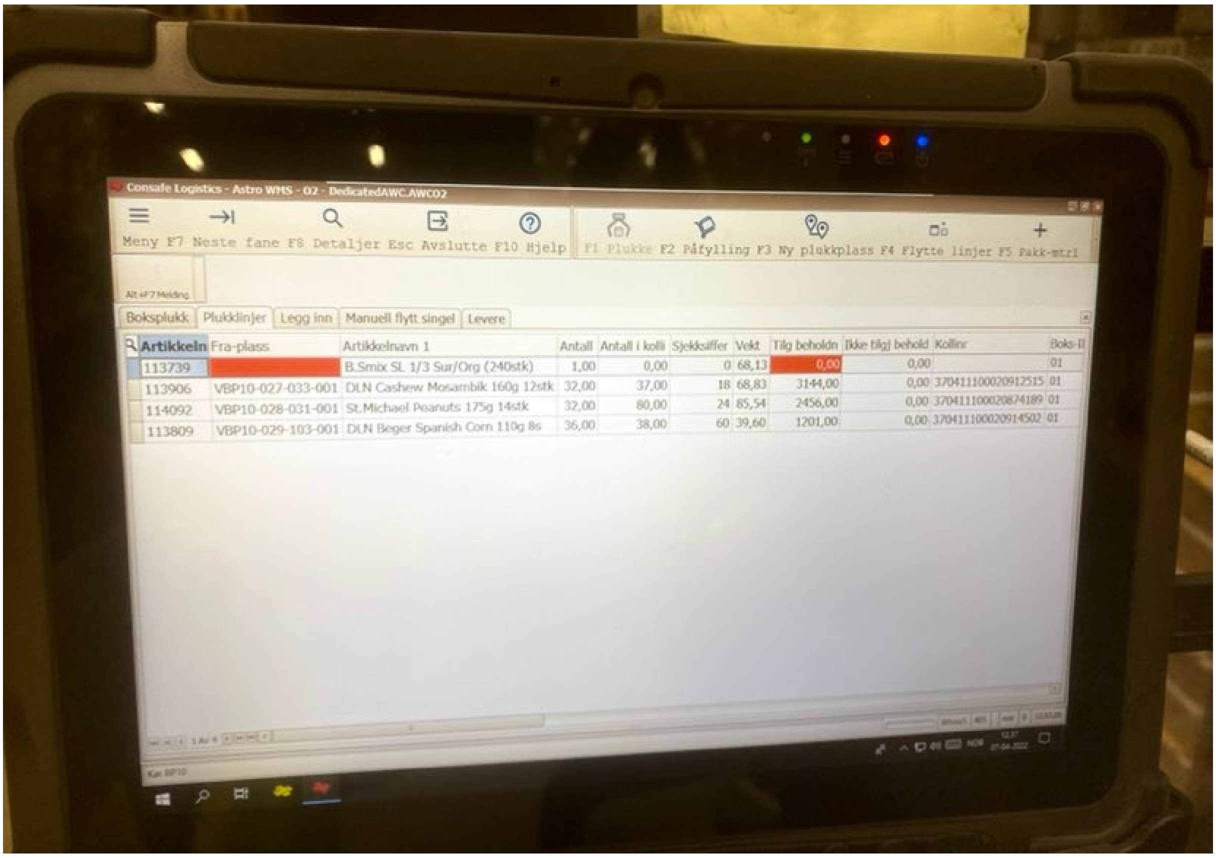


Figure 4.8: An image of the screen attached to the forklifts used by the operators. Here, an order is shown with four picking-lines. The lines contain information about the different products in the order, including storage location, name, amount to pick and amount available, weight, etc.

In Astro, the automatic selection of locations is based on the following three alternatives:

- *Location automatic:* The suggestion is usually based on the SKU definitions and an algorithm defined by the location spread logic (Table 4.4) and the location search logic (Table 4.5). Other types of logic may also exist such as location type and weight.
- *Auto, prompt rack:* In the put-away functionality, the operator can press "next" to be requested a new rack instead of verifying the automatically suggested location.
- *Auto, same aisles as pick area:* The location search is on the same side of the aisle as where the picking location is located. This should be used in cases with narrow aisles and picking in level 0, with buffer area in the rest of the levels.

Additionally, Astro considers the following factors when searching for storage locations: weight restrictions (i.e. on single storage locations) and maximum weight of a section. If no storage location is found after the search in Astro, the operator must manually find an alternative storage location within the warehouse.

Spread Logic	Description
Near last location	The system searches for a new storage location close to the last one used for the put-away for the same SKU.
Even over the rack	The system spreads unit-loads evenly over the rack.
Even over the aisles	The system spreads unit-loads evenly over the aisles.
Defined location of the SKU	The predetermined location suggested for each SKU.
The first free location	The system search from the first storage location in the storage area.
Against the location of a defined SKU	The search starts from a specified location and searching forward. The system searches all available storage locations in the storage area but always starts from a defined X and Y coordinate. The search will never check for storage locations before the defined X and Y coordinates.

Table 4.4: WMS location spread logic, adapted from the functional description of Leman's WMS.

Search Logic	Description
Rack+	The system will increase the rack number (search in the next rack, and next, and so on until all racks in the area have been searched).
Location type+	The system will search in the current rack and look for a location of the alternative location type(s).
Rack+, location type+	The system will first search in all the racks (Rack+) and then for alternative location type(s) (Location type+) in all the racks.
Location type+, rack+	The system will first search for the alternative location type(s) in the current rack, and then in all other racks.

Table 4.5: WMS location search logic, adapted from the functional description of Leman's WMS.

4.2.7 Order Process

The orders from Brynild's customers constitute the outgoing goods and can be categorized into two types: instant orders and pre-orders. The instant orders are handled immediately after the orders are received by Leman, and concerns goods that are to be shipped shortly after ordering. The pre-orders have longer time horizons and can be received several weeks or months before they are shipped.

For the instant orders, Leman operates with the terms day 0, day 1, and day 2. The instant order process is described in Table 4.6. If an instant order is received after 10:00 AM one day, then day 0 for that order will be the next day instead. However, Brynild has the option to pay extra for express shipping. If that is the case, the order can be included in day 0 even if it is received by Leman after 10:00 AM. The day 0, 1, and 2 system is based on the workdays at Leman which are Monday to Friday. I.e., if an order is received before 10:00 AM on a Friday, then day 1 is the next Monday.

Day 0	Day 1	Day 2
The order is received by Leman before 10:00 AM.	The order is picked by an operator and prepared for shipping.	The order is retrieved by a truck.

Table 4.6: An overview of the process at Leman after receiving an instant order.

4.2.8 Cost and Price Structure

As Brynild is a customer of Leman, they have to pay for all the services they use at Leman. The price structure is based on the different activities Leman performs, such as IFP, OFP, OMP, storage, wrapping, unloading of goods, reception of goods and other warehousing activities. Some of the activities are based on the amount of time the activity takes, such as storage time (how long the pallets are stored). These storage prices are charged per pallet per day, and the price also depends on the size of the pallet. Other activities are based on e.g., the number of pallets handled, or cartons picked. This includes all the standard activities performed (IFP, OFP and OMP). An excerpt of the prices charged by Leman from Brynild is shown in Table 4.7.

4.2.9 Staffing

Permanent Workers

There are currently 8 permanent, full-time operators working at Leman's warehouse in Vestby. They all work day shifts from 07.00 to 15.00 from Monday to Friday every week. These employees perform all the normal operations in the warehouse as described in section 4.2.2. At the Brynild department of the warehouse, there are usually 3-4 operators:

- 1 operator: Handling IFP and OFP along with raw materials.
- 1 operator: Handling OFP of finished goods.
- 1-2 operators: Handling OMP.

All of the 8 operators in the warehouse have some knowledge about the different products and storage locations (Brynild and the 12 other companies), but the level of experience varies. Therefore, the operators with the most experience with Brynild's products are usually working in the Brynild section, to increase the effectiveness. Some of the operators have expertise in picking and assembling mixed pallets (OMP) while others have more experience with full pallets (OFP and IFP). Currently, all the operators have worked at the facility for between 4 and 30 years.

The full-time operators have an hourly wage of NOK 219.82 per hour. For operators who have been employed for 5 years or more, there is a wage supplement of NOK 3 per hour. A truck certificate gives a wage supplement of NOK 2.62 per hour.

Activity	Price (NOK)	Unit
Storage rentals		
Pallet 120 x 80 x 120	2.12	per day
Pallet 120 x 80 x 180	3.41	per day
Pallet 120 x 80 x 240	4.54	per day
Pallet 120 x 120 x 120	3.41	per day
Pallet 120 x 120 x 180	4.54	per day
Pallet 120 x 120 x 240	6.80	per day
Pallet 220 x 120 x 120	9.08	per day
Receiving		
Unloading of pallets (unless handled by driver)	36.61	per pallet
Unloading and control of loose goods	29.49	per pallet
Down palletizing	48.82	per pallet
Pallet labeling	2.03	per label
Shipping		
Outbound handling of pallet (120 x 80 x 125)	26.84	per pallet
Outbound handling of carton	1.85	per carton
Outbound handling of single item	1.02	per item
Packing		
Wrapping of pallet (shrink wrap)	20.70	per pallet
Other		
Express surcharge (ready for shipping within 1 hour)	747.50	per order
Express surcharge (ready for shipping same day)	517.65	per order
Services not specified between 0700-1500	448.50	per hour
Hourly rate 1500-2100, 0600-0700	673.25	per hour
Hourly rate 2100-0600	896.99	per hour
Invoice fee	86.45	per invoice
Container emptying 20 ft	2130.62	per container
Container emptying 40 ft	4254.11	per container
Booking of transport (unless with Leman transport)	134.24	per transport
Customs clearance including 1 tariff line	517.65	per clearance

Table 4.7: An excerpt of the prices Leman charges Brynild for their warehousing activities provided by Leman's warehouse manager. All prices are excluded VAT.

Temporary Workers

In addition to the permanent workers, Leman uses a temp agency for hiring temporary workers when needed. These workers can be divided into two groups: full-time and part-time workers.

Leman usually has 0-2 full-time temporary workers who are hired on either weekly or monthly contracts, depending on seasonal variations and demand. These have fixed working hours and often work on the same operations as the permanent workers.

In addition, Leman hires part-time temporary workers when needed. These workers rarely work with the standard warehouse operations (IFP, OFP, and OMP) because this requires training with all the internal systems and the WMS system. These temporary workers are therefore hired in periods with higher activity levels for the other activities than the standard ones, so there is less pressure on the full-time operators. These activities involve creating sales solutions, container unloading, repacking of goods, etc.

Leman has used the same temp agency for about 4-5 years, and they often get back temps who have worked for them in the past. If Leman receives a temp that has never worked for Leman before, they get 3 days of training. After the training days, the worker should be independent and able to perform all activities on their own.

The hourly wages of the temporary workers are unknown, but Leman pays the temp agency NOK 314 per hour for each worker, and then the agency pays the workers. The lead time for hiring the temps is 1 day.

Voluntary Workers

The last employment type are voluntary workers, who are organized and hired by Brynild. They use an area in Leman's facility after the regular working hours, and they mainly work with sales solutions such as store displays for the retailers.

4.2.10 Capacity Planning

The capacity at Leman is planned based on the factors and parameters shown in Table 4.8. For the permanent workers, there is no need to plan the working hours because they are standardized. What needs to be planned for the permanent workers are where they should work within the warehouse and with what operations. The activity levels vary by season and for the different companies in the warehouse. This means that an operator can perform activities for Brynild one day, and for another company the next day, based on the activity level. As mentioned, there are usually 3-4 workers in Brynild's section, and these are quite fixed. In periods with higher or lower activity levels, the operations manager either moves more operators to the Brynild section or moves some of them to other parts of the warehouse, based on the need. Here, the operations manager considers the experience level of each operator and uses the operators for the tasks they each have the most expertise in performing.

The operators, in addition to being responsible for specific activities, are responsible for monitoring the activity levels within the warehouse daily. This is done by using the WMS system on the screens connected to their forklifts. If the activity level suddenly is very low in an operator's responsibility area and very high somewhere else in the warehouse, the operator can move to that area and perform activities there.

The hardest employee type to plan the capacity of is usually the temporary workers. Because of the lack of forecasts and production plans from Brynild, Leman faces some challenges regarding when the temporary workers are needed and not. The operations manager usually has knowledge about the need for temporary workers one day in advance, or early in the morning the same day

<table>
<tr><th>Type of employment</th><th>Permanent</th><th colspan="2">Temporary</th></tr>
<tr><th>Type of appointment</th><td colspan="2">Full-time</td><td>Part-time</td></tr>
<tr><th>Quantity</th><td>8</td><td>0-2</td><td>4-10</td></tr>
<tr><th>Operations</th><td colspan="2">IFP, OFP, OMP, wrapping, labeling, up/down palletizing</td><td>Sales solutions, container unloading, repacking of goods</td></tr>
<tr><th>Shift model</th><td colspan="2">Day-shift (5 work days/week)</td><td>Variable</td></tr>
<tr><th>Operating hours</th><td colspan="2">7.5 hours (07:00 - 15:00) with 30 min break</td><td>Variable</td></tr>
<tr><th>Shift's break hours</th><td colspan="2">1x 30 min (11:30 - 12:00), 2x 10 min</td><td>Variable</td></tr>
<tr><th>Shift's effective hours</th><td colspan="2">7 hours and 10 minutes</td><td>Variable</td></tr>
<tr><th>Holidays</th><td>5 weeks (+1 week for workers aged over 60)</td><td colspan="2">N/A</td></tr>
<tr><th>Wage</th><td>NOK 219.82 per hour</td><td colspan="2">N/A</td></tr>
<tr><th>Five years premium</th><td>+ NOK 3 per hour</td><td colspan="2">N/A</td></tr>
<tr><th>Truck certificate</th><td>+ NOK 2.62 per hour</td><td colspan="2">N/A</td></tr>
<tr><th>Agency costs</th><td>N/A</td><td colspan="2">NOK 314 per hour</td></tr>
<tr><th>Recruitment lead time</th><td>N/A</td><td colspan="2">1 workday</td></tr>
<tr><th>Training lead time</th><td>N/A</td><td colspan="2">3 workdays</td></tr>
<tr><th>Retention time</th><td>3 months</td><td colspan="2">1 week</td></tr>
<tr><th>Sickness policy</th><td>3 days</td><td colspan="2">Covered in factor</td></tr>
<tr><th>Sickness estimate</th><td colspan="3">2 - 2.3 % per year</td></tr>
</table>

Table 4.8: An overview of the parameters used in the capacity planning.

as they are needed, which gives a very short time horizon for the planning.

4.3 Analysis of the Current Situation

In this section, the current situation at Leman is analyzed. First, several challenges and improvement areas related to the order picking process are identified. Then follows an analysis of the order picking patterns and the demand patterns at Leman, based on historical data.

4.3.1 Challenges and Improvement Areas

Through interviews with the logistics management and the warehouse operators at Leman, some challenges and weaknesses related to the current warehouse principles and warehouse operations were identified and several none-verified reflections were made. This section describes and discusses these challenges.

1. The WMS does not comply with two unit loads being transported at the same time

The WMS does not comply with warehouse operators putting away two unit loads at the same time. As previously mentioned, the warehouse operators sometimes load two unit loads at the inbound area in an attempt to reduce the travel time of the put-away operation. However, the process in which this is currently completed can actually lead to an increase in the travel time. First, the warehouse operator scans the upper unit load, the WMS assigns a storage location for that unit load and the warehouse operator puts the upper unit load in the storage location suggested by the WMS. Then the warehouse operator scans the lower unit load and the WMS assigns a storage location for that unit load. The issue is that the WMS does not consider the first movement of the unit load. That is, the WMS believes that the lower unit load and the operator is in the I/O area. As previously mentioned, this can lead to additional travel time from the location where the warehouse operator left the upper unit load to the location, suggested by the WMS, to the lower unit load. Consequently, the warehouse operators are often tempted to overrule the warehouse principles and place the lower unit load in at storage location close to the storage location of the upper unit load, instead of following the instructions given by the WMS. This is problematic because the lower unit load might then end up being stored in the wrong storage zone.

2. Inefficiency caused by fast moving SKUs

Fast moving SKUs can often cause an unnecessarily high amount of travel time. This happens in cases when incoming SKUs are put-away from the I/O area to a storage location, and then those same SKUs are picked and brought back to the I/O area all in a short time interval. According to the IT manager, the SKUs are often put away in storage location far away from the I/O area. This issue leads to inefficiency in the Leman warehouse.

3. The WMS does not consider proximity to outbound location in the order picking process

The choice of location at the I/O area for an outbound order can lead to unnecessarily long travel times in the order picking process. Before an outbound order is released to the warehouse operators, the Leman employees at the order office choose an outbound location in the I/O area. When the outbound location is chosen, the location's proximity to the SKUs included in the order is not considered. For Brynild's SKUs an outbound location in Brynild's designated storage area is preferred, but if no outbound location is available in this area, an outbound location in another storage area is chosen.

The WMS does not consider the outbound location of an order when it selects which pallets should be picked for an order. After an order has been released, the WMS automatically chooses the pallets located in the lowest vertical location, and does not take into account which pallets are located closest to the outbound location.

4. Inefficiency due to FEFO and batch requirements

In some cases, inefficiency can occur due to a combination of the FEFO principle and batch requirements. According to the order pickers, this happens in situations where a full pallet of a SKU is ordered, and the carton picking area contains a half-full pallet of the first expiring batch. In these cases, the order picker must pick the half-full pallet, before picking another half-full pallet from another batch with an empty pallet in between. This leads to an increase in the order throughput time. On the one hand, Leman claims that they have been told to comply with both principles and thus to do this regardless of the cost. On the other hand, Brynild was not aware that complying with these two principles causes operations to be more expensive.

5. Pallet replenishment for mixed pallet picking

The order pickers at the Leman warehouse experience that replenishing the carton picking locations can be time consuming. The carton picking is located at the bottom shelf in designated carton picking areas. When a pallet is emptied in a carton picking location, this location must be replenished. The pallets for replenishment are often stored in other aisles than the carton picking locations, at high altitudes. As previously mentioned, the trucks used for carton picking can only reach the two bottom shelves, thus, the order pickers picking cartons cannot always replenish the carton picking locations themselves. Consequently, they must often interrupt colleagues to ask them for assistance. If the order picker picking cartons is in the middle of an order when the need for replenishment occurs and the replenishment stock is out of reach, the order picker must find a colleague and wait for the colleague to replenish the carton picking location before resuming the carton picking process. In addition, according to the warehouse operators, the pallet truck used for carton picking moves slower than the forklift used to transport full pallets. This leads to inefficiency both for the order picker picking cartons and the forklift operator who is asked to assist him/her.

The issues described above indicates that there is a mismatch between the WMS and the warehouse operations that leads to an increase in the order throughput time. This is found to be because of several reasons. Firstly, the scale of the warehouse does not require anyone to be solely assigned to replenish the picking area. As previously mentioned, Leman has three permanent workers assigned to Brynild's SKUs with different responsibilities. When a warehouse operator starts a shift, he/she logs into the system and chooses between the four following functions; put-away, moving full pallets to the I/O area (picking full pallets), carton picking and replenishing the carton picking area. When a carton picking location is emptied, the WMS places an order for this location to be replenished. This order is only given to a warehouse operator who has chosen the replenishment function. As there are no operators permanently logged into the replenishment function, this causes inefficiency as described above.

Secondly, Leman has a five year lease contract on trucks aligned with client contracts. Thus, there is currently a mismatch between operations and equipment. Finally, the WMS logic does not consider the location of the carton picking area for the given SKU, when assigning where it should be replenished from. The search for replenishment of the carton picking area follows the FEFO principle and the WMS searches for the replenishment pallet closes to the current storage location. However, the order picker tasked with replenishment experiences an unnecessarily long travel distance because the storage location assignment logic, applied by Leman, does not take into account where the carton picking location for the given SKU is located.

6. High fill rate decreases efficiency

The fill rate of the warehouse influences the efficiency of the warehouse operations. According to the operations manager at Leman, if the fill level in the warehouse gets too high problems related to efficiency occurs. Figure 4.9 describes the average fill rate in the Brynild designated area for the period January 2015 to September 2021. The average fill rate varies each month with an, with an average of 75.61 %. The figure shows an increase in the fill rate from the middle of 2020 an onward. This results show that Leman has to either expand their warehouse or eliminate the efficiency problems related to a high fill rate.

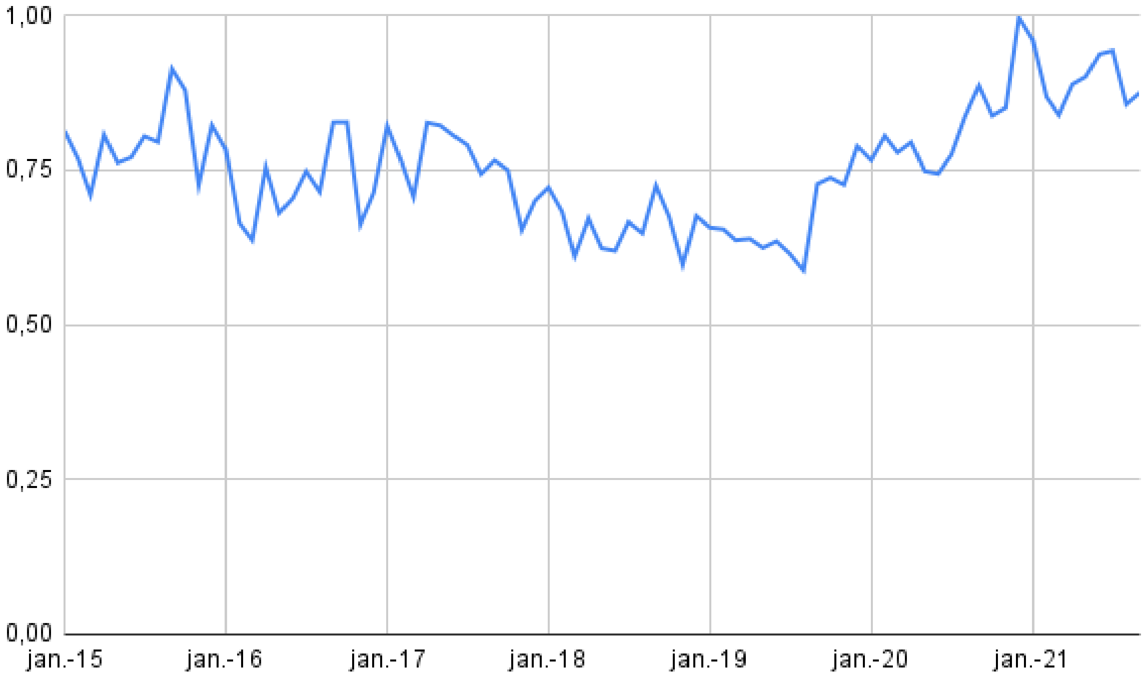


Figure 4.9: The average fill rate each month in the period January 2015 to September 2021, adapted from Leman's KPI reports.

Leman is currently in the process of expanding their warehouse and the fill rate might decrease as a result. However, this may only be a short term solution. The expected growth described in the previous section and the fact that Leman cannot expand any more than the current expansion, shows that this issue may reoccur in a short time. In addition, according to the literature, low space utilization is a source of waste and should be eliminated. This indicates that Leman's current storage policy is not optimal.

7. Transportation logistics issues

The operations manager also mentioned some issues with the transport logistics that are relevant when examining the possibility of reshuffling in the warehouse. The general rule at Leman is currently that all truck drivers are supposed to notice Leman about their expected arrival 24 hours in advance. According to the operations manager, this is not always done in practice. He stated that the trucks with incoming goods often show up without notice, which makes the workload prediction more difficult. Also, many of the trucks only give notice about which day they arrive, but not the specific time during the day. Even though Leman assigns different time slots for each truck, the trucks do often not arrive when expected. Some trucks also arrives at different days than planned, and some do not show up at all. Also, one of the loading ramps at Leman is reserved for a truck going continuously back and forth between Leman and Brynild transporting the incoming goods from Brynild's own factory. The operations manager does not have any information about the timing of this truck.

8. Order congestion

In the periods with highest activity levels, Leman faces some issues with congestion of the outgoing goods. The goods that are picked for the orders are, as previously stated, moved to the I/O area. This area has limited space, and during high activity periods it often becomes completely filled. The trucks are often showing up late or at other times than expected, and this is especially a problem during these periods. When the I/O area is full, the operators cannot continue with order picking until the trucks show up and remove some of the goods from that area. The trucks often show up late in the day, which means that some of the orders cannot be picked before then. If these remaining orders must be ready for delivery the next day, the operators have to pick these orders after the regular working hours. This leads to both more idle time and more overtime work for the operators, and is a frequent issue. This issue is closely related to the previous issue because it is also dependent on the transportation logistics.

9. Limited overview of the demand pattern

One of the main issues with the storage location assignment at Leman is the inaccuracy of the forecasts from Brynild about incoming goods. Currently, Leman receives a forecast in the form of a production plan from Brynild's factory in Fredrikstad every four weeks. However, according to the operations manager, these forecasts are usually not very accurate and does not reflect the actual amounts and the timing of incoming goods from Brynild and the other factories.

According to Leman, Brynild does not notify them of campaigns. As previously mentioned, campaigns increase Leman's workload with spikes in both incoming shipments and outgoing orders. As the ABC classification is only updated approximately every 14 days, and Brynild does not communicate to Leman that a campaign is imminent, the campaign products may end up being wrongly classified. This is the case even though Brynild is aware of the campaign demand four to eight weeks before the campaign starts. Leman's limited overview of the demand patterns of Brynild's products can thus lead to an increase in order throughput time.

Furthermore, Leman does not receive any pre-orders on new products from Brynild. Thus, to solve the SLAP for new products, all new products are classified as A products. This can lead to issues as this classification may be wrong. The limited amount of storage locations in each zone can result in increased travel time, because new products occupy the best storage locations even though they are not in high demand. Thus, the order picker will have to travel more frequently to less desirable storage locations in zone B and C. It is also important to note that Leman has no information on what type of seasonality SKU this new product is classified as. This is problematic for Leman, as understanding the demand pattern of Brynild's SKUs is key to the storage location assignment.

Another issue for Leman is that the SKU classification is based on historical data. This is problematic, because the WMS is too slow to react to seasonal variations. Leman solves this by having the IT manager manually adjust the classification of SKUs to adhere with seasonality. However, due to the limited amount of information sharing between Leman and Brynild, the IT manager has little information to support his decision making and mostly bases his decisions on experience.

10. Unknown order types

Leman receives some forecasts of the predicted sales from Brynild, which possibly can give an indicator of the future outbound orders concerning the outgoing goods. However, these predictions include only the amounts of the different product types and does not include the predicted types of orders. There are two order types: full pallets and mixed pallets. As previously stated, the order picking process is a lot more time consuming for mixed pallets than for full pallets because it requires more traveling. The order types therefore highly affects the travel time which makes it difficult to use these forecasts when classifying the SKUs from Brynild and assigning them to a storage location.

11. Lack of systematization

Another potential challenge at Leman is the lack of systematization in several areas concerning the operators and the workloads. Currently, most of the information about the different operators, such as their skills, preferences and experience levels, are not systematized. The operations manager has a lot of knowledge in his head about the operators based on his experience, as he has worked at Leman for many years and knows the operators well. This information involves the picking speed of the individual operators, their experience level, and which operations they have most expertise in and prefer to work with.

The operations manager also has experience-based knowledge about the seasonal fluctuations in demand because the seasonal demand is somewhat similar from year to year. For instance, he knows that the workloads are much higher in some specific months before Christmas and Easter every year, and therefore hires extra temporary workers during these periods. All of this information makes it easier for the operations manager to predict the demand and perform the storage location assignment, but for someone without this knowledge it would be more challenging.

Summary of the Challenges

The identified challenges related to Leman's order picking process are summarized in Table 4.9. The analysis of the challenges revealed that the source of their challenges are mainly related to the WMS logic, poor information flow in the supply chain, and the demand variations. The majority of the consequences causes a decrease in efficiency and an increased order throughput time. The findings show that it is necessary to further investigate the picking patterns and demand patterns to understand how Leman could benefit from implementing reshuffling in their operations.

Challenge	Source	Consequence
1	WMS logic	Increased travel time SKUs stored in wrong zone
2	WMS logic	Unnecessary transportation of SKUs
3	WMS logic	Increased travel time
4	WMS logic Warehouse principles	Increased order throughput time
5	WMS logic Use of trucks	Increased order throughput time
6	Storage policy Increased demand	Decrease in efficiency
7	Poor information flow	Workload uncertainty
8	High demand Transportation logistics	Increase in idle time and over-time
9	Poor information flow Demand fluctuations	SKUs classified wrongly
10	Poor information flow	SKUs classified wrongly
11	Lack of systematization	Leman is reliant on a few individual employees

Table 4.9: Summary of Leman's key order picking challenges, their main sources, and relevant consequences.

4.3.2 Picking Patterns

To locate where the reshuffling should take place, the picking patterns were studied in combination with the warehouse layout.

First, the total number of S/R cycles in 2019, 2020, and 2021 for each of the classes A, B and C were calculated. The percentage distribution is shown in Table 4.10. The results show some variation in the number of S/R cycles in each zone from year to year. The results for the year 2021 show that, compared to the Pareto principle described in Section 3.5.1, the percentage of S/R cycles in zone A is almost 10 % less than it should be. This could be unfortunate for the warehouse efficiency. The number of S/R cycles for zone A is much greater than the number of S/R cycles for zone B, and the number of S/R cycles for zone B is much greater than the number of S/R cycles for zone C, for all three years. This is in line with the principles of the ABC classification method. However, compared with the method description from the literature this is not an optimal distribution of S/R cycles per zone.

To get an overview of the relationship between carton picking and full pallet picking, the number of S/R cycles for each type of picking for each of the classes were calculated. The results for 2021 are shown in Table 4.11. The data from 2019 and 2020 yield very similar results. Thus, the data from 2021 can be viewed as representative.

The results show that 55 % of the S/R cycles in the picking operation is accounted for by the

Class	% of S/R cycles		
	2019	**2020**	**2021**
A	73.2 %	68.1 %	70.3 %
B	19.0 %	21.2 %	21.3 %
C	7.8 %	10.7 %	8.4 %

Table 4.10: Percentage of S/R cycles in each class A, B and C.

full pallet picking. The picking from the A zone is evenly distributed between the carton picking and the full pallet picking. However, for zones B and C there is an overweight of full pallet picking. Full pallet picking is responsible for 61 % and 88 % of the S/R cycles, for zones B and C respectively.

For the carton picking, approximately 79 % of the S/R cycles are attributed to the A zone, approximately 19 % of the S/R cycles are attributed to the B zone and approximately 2 % of the S/R cycles are attributed to the C zone. These results concur with the information found in the literature. For the full pallet picking, approximately 63 % of the S/R cycles are attributed to the A zone, approximately 24 % of the S/R cycles are attributed to the B zone and approximately 13 % of the S/R cycles are attributed to the C zone. This is not ideal, especially as full pallet picking accounts for the majority of the picking operation.

Class	Carton picking	Full pallet picking	Total
A	22 010	21 754	43 764
B	5 136	8 137	13 273
C	644	4 558	5 202
Sum	27 790	34 449	62 239

Table 4.11: Number of S/R cycles for the different classes A, B and C during order picking of mixed pallets and full pallets in 2021.

Another important aspect of the picking patterns is the distribution of S/R cycles over the racks. Thus, the number of S/R cycles for both full pallet picking and carton picking for each of the relevant racks were plotted for the year 2021, as shown in Figure 4.11. In order to investigate whether the results found for 2021 are representative for the normal warehouse operations and not anomalies, the total amount of S/R cycles per rack for 2019, 2020 and 2021 were also plotted in Figure 4.10. The figure shows that the amount of S/R cycles per rack is similar for each included year. Thus, conclusions about Leman's picking patterns can be drawn from Figure 4.11.

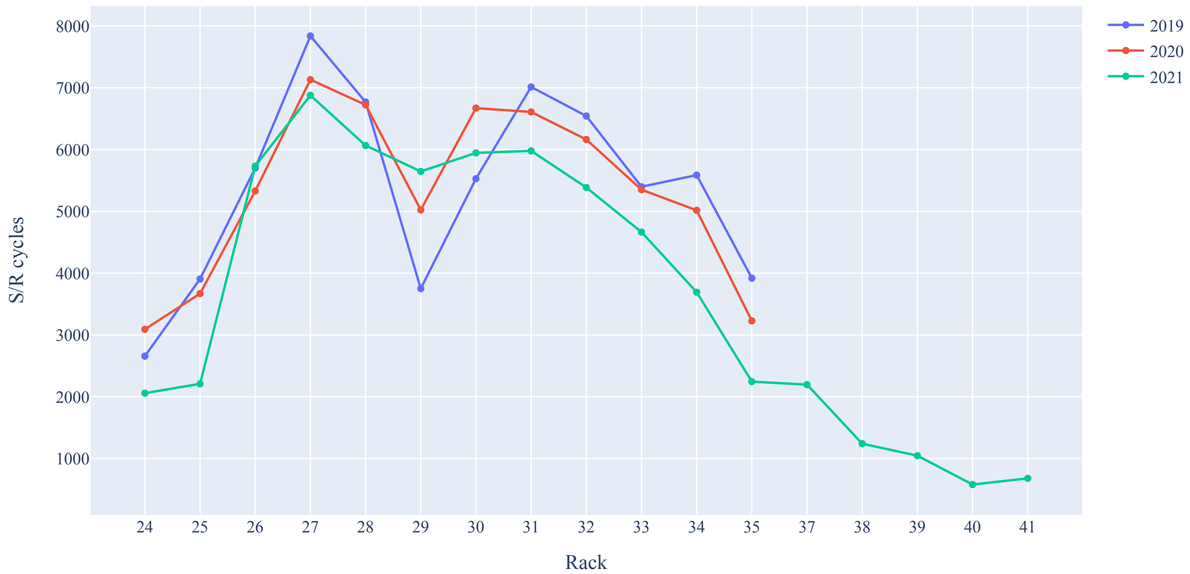


Figure 4.10: The total amount of S/R cycles per rack in 2019, 2020 and 2021.

Note that rack 36 is not included in Figure 4.10 and Figure 4.11. This is because none of the relevant zones are located there. Rack 36 only stores raw materials, which are not classified as A, B nor C. There are 428 different SKUs in this data set when racks 24 to 41 is examined and only S/R cycles related to picking SKUs from zone A, B or C is included.

Furthermore, there are no S/R cycles on racks 37 to 41 for the years 2019 and 2020 in Figure 4.10. This is because these racks did not exist at the time. This can probably explain why the average amount of S/R cycles per rack 24 to 35 have decreased in 2021, as some of the S/R cycles have been moved to the new racks. Despite of this, the distribution over the racks 24 to 35 is still similar to the distributions in 2019 and 2020.

Figure 4.11 shows the distribution of S/R cycles per rack separated into full pallet picking and carton picking. The plot clearly shows that rack 27 is most frequently traveled to, both for carton picking and full pallet picking. Racks 31 and 30 hold the second and third place respectively, followed by racks 28 and 29. There are eight racks with a total amount of S/R cycles less than 1000, for the year 2021. Thus, the S/R cycles are not evenly distributed between the racks. The main reason for the low amount of S/R cycles for rack 35-41 is that they mostly consist of raw materials and packaging materials, etc.

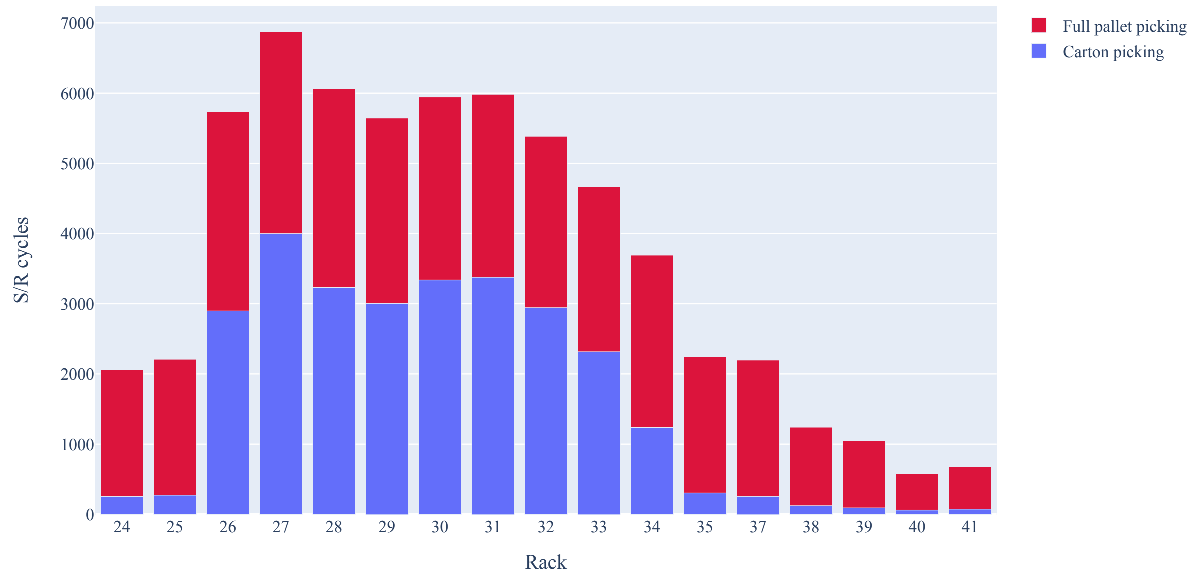


Figure 4.11: The total amount of S/R cycles per rack in 2021 for carton picking and full pallet picking.

As visualized in Figure 4.11, rack number 27 is clearly the rack which is most frequently picked from. Thus, this rack was investigated further to look at its patterns. First, the total amount of S/R cycles for rack 27 for full pallet picking and carton picking in 2021 were plotted in Figure 4.12. The results show that a minority of the bays account for a majority of the S/R cycles. Furthermore, the majority of the S/R cycles go to the bays closest to the I/O area. This is not surprising as the bays closets to the I/O area have more desirable locations with shorter travel time. However, there are some surprises in these results. First, the six bays closest to the I/O area each have about 100 S/R cycles less than the most popular bay. Second, even though they are surrounded by popular bays, bay 052 and bay 072 can account for very few S/R cycles. Third, while bay 103 has the second highest number of S/R cycles for rack 27, the number drastically drops on the next bay and stays very low, with slight variations, for the remaining bays.

Another interesting find is that while the majority of the S/R cycles related to carton picking is skewed towards the I/O area, the S/R cycles related to full pallet picking is more evenly distributed among all the bays of the rack. This can partly be explained by looking at the zone locations, which are different in the carton picking area and in the full pallet picking area. As shown in Figure 4.5, the classes A and B are present in all shelves 2 to 6, and zone A cover more of the bays in the full pallet area than for the carton picking area, on average. Also, the travel time differs between the two areas, because for the full pallets, vertical travel time must be included. Thus, it might be beneficial to use a larger amount of the bays for full pallet picking than for carton picking.

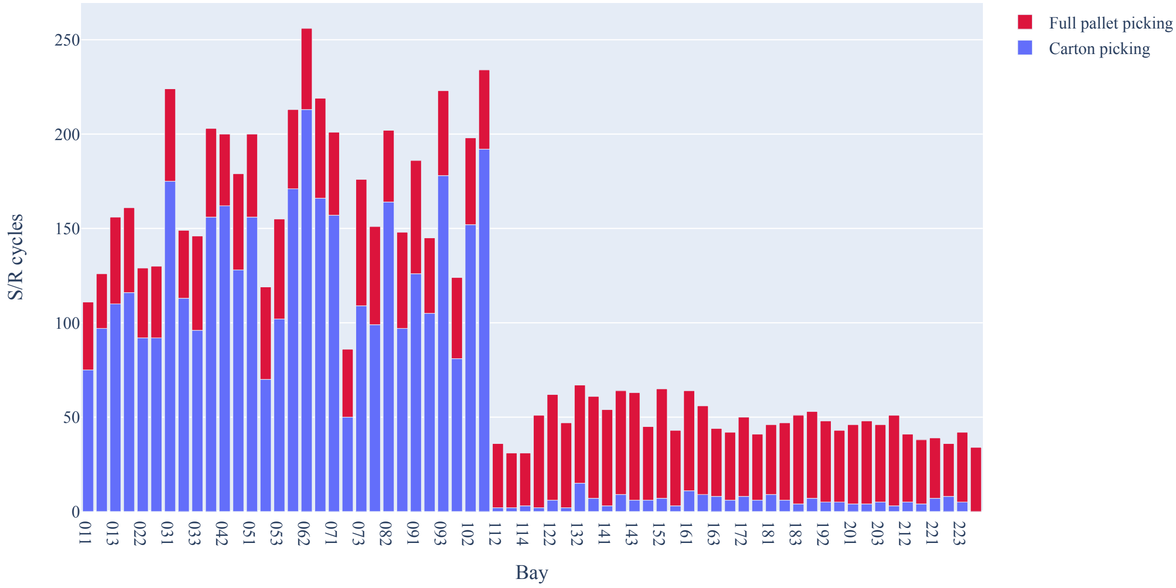


Figure 4.12: The total amount of S/R cycles per bay for rack number 27 in 2021 for carton picking and full pallet picking.

To investigate the patterns in the carton picking area, the amount of S/R cycles per bay for shelf number 1, in rack 27, were plotted, as shown in Figure 4.13. The number of S/R cycles for bay 111 to 163 is very low, even though the majority of the shelves in the bays are zone A locations. This is surprising as the A zone should be picked from much more frequently than zones B and C. This is the case for the overall picking situation in the warehouse, as described in Table 4.10. However, examining the picking patterns for a single rack again shows that the storage policy applied by Leman is not optimally solving the SLAP. Either the classification of the storage locations into zones is inadequate, or the classifications of SKUs into the zones is inadequate. If it is the latter, this problem could be caused by the fact that SKU classifications are not updated frequently enough.

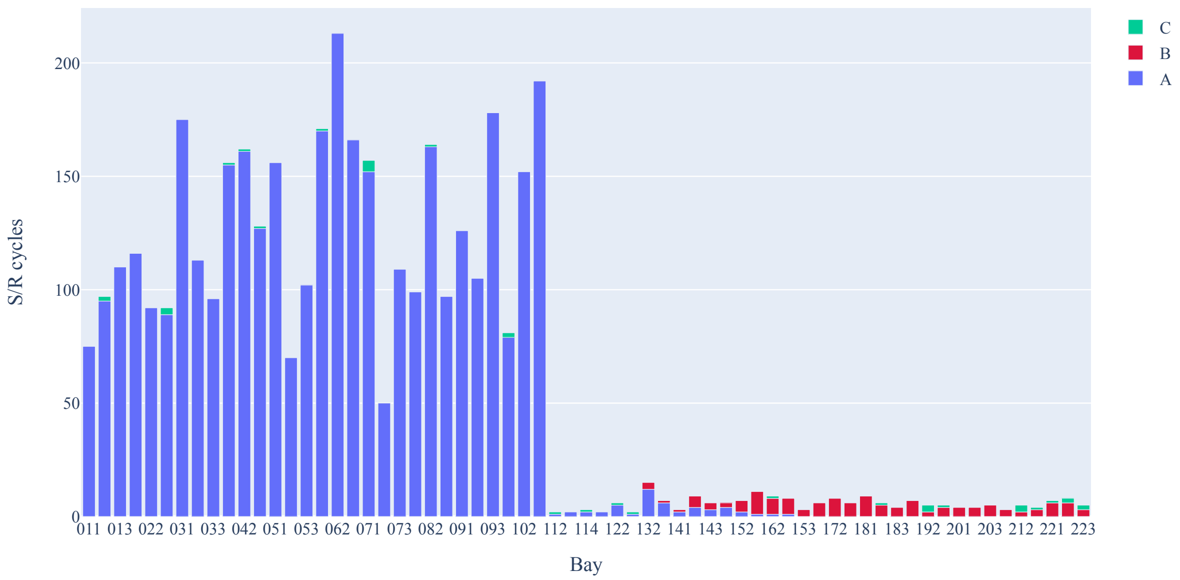


Figure 4.13: The total amount of S/R cycles per bay for rack number 27 in 2021 for the carton picking in each class A, B, and C.

To investigate the picking patterns for the full pallets, the S/R cycles per shelf for rack number 27 were plotted, as shown in Figure 4.12. The results show that the amount of picks per class A and B is quite evenly distributed on the shelves 2, 3, 4, 5, and 6. Class C is only picked from in shelf 3, 4, 6 and 7. There are no picks for shelf number 8. However, this distribution makes sense when looking at the zone locations for the shelves, as shown in Figure 4.5. This is because the classes A and B are present in shelves 2-6, and shelf number 7 only consist of class C. Shelf number 8 does not contain any of the classes A, B, or C, and is therefore not picked from. Although, is surprising that the lowest shelves are not most frequently picked from, as they have shorter vertical travel distances and are therefore more efficient.

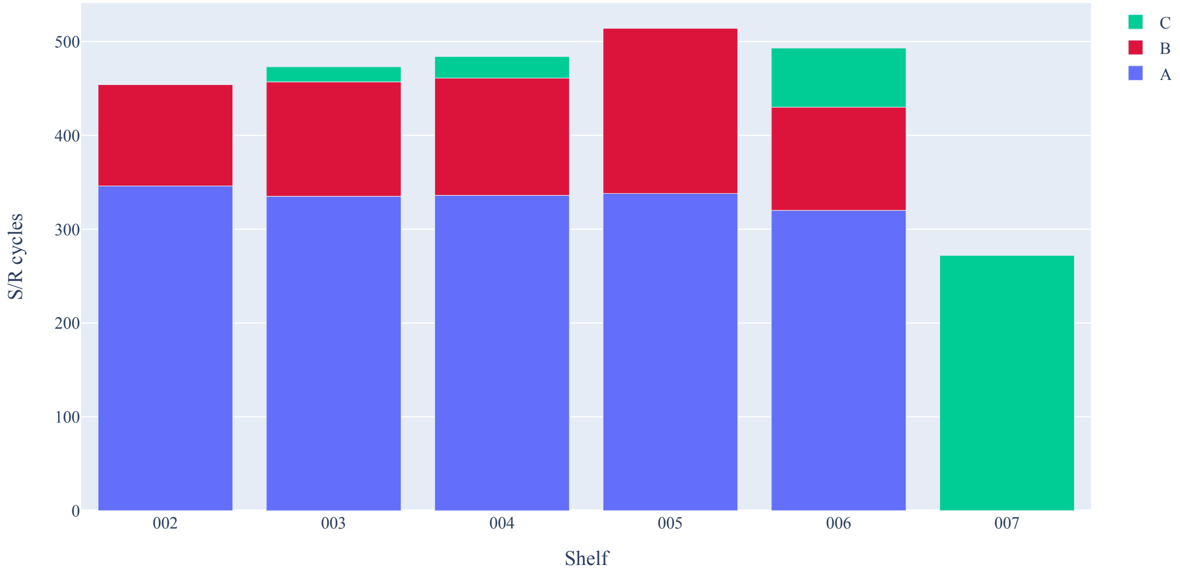


Figure 4.14: The total amount of S/R cycles per shelf for rack number 27 in 2021 for full pallet picking in each class A, B, and C.

To investigate if the pattern for shelf 2-8 is similar for the other racks, a plot of the total number of S/R cycles for each shelf were made. Here, the S/R cycles for all racks (24-41) from the years 2019, 2020, and 2021 were included. The plot is shown in Figure 4.15. The plot yield similar results as for the shelves in rack number 27: the shelves 2, 3, 4, 5 and 6 are most frequently picked from, and they have a very similar number of S/R cycles per shelf. The number drastically decreases for shelf 7 and is very low for the top shelf, like for rack 27. This is because the top shelf is used mostly for storage of raw materials and packaging materials. Shelf number 7 only contains the zone C for all racks, which can be a reason for the low number of S/R cycles.

The plot in Figure 4.15 indicates that there is a pattern for the number of S/R cycles per shelf at the Leman warehouse. This is because the results for 2019, 2020 and 2021 are very similar. Note also that when the plot is examined in detail, it is clear that the number of S/R cycles for both shelf 3 and 4 is higher than the number of S/R cycles for shelf 2. This is surprising as the order throughput time increases if a pallet is retrieved from shelf 3 or 4 rather than shelf 2, if the shelves are located in the same bay. Thus, the results in the figure indicate that the order throughput time can be decreased through the use of goods reshuffling.

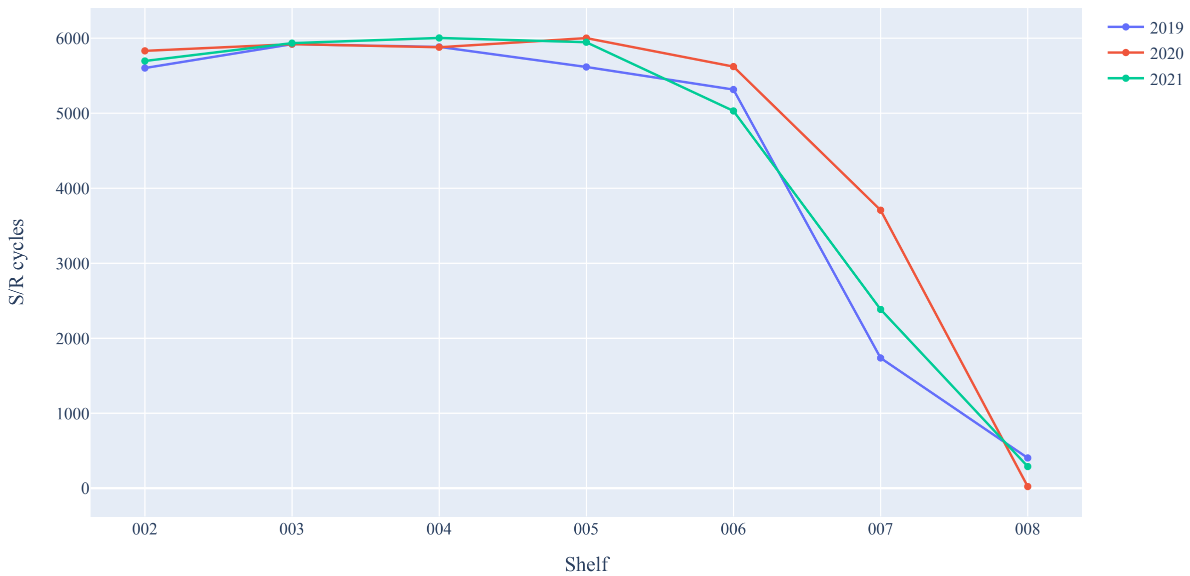


Figure 4.15: The total amount of S/R cycles per shelf for shelves number 2 to 8 (used for full pallet picking).

Summary of the Picking Patterns

- Leman has some clear picking patterns.
- Full pallet picking accounts for 55% of the S/R cycles.
- The distribution of S/R cycles over the different classes is not ideal with a lower than recommended number for zone A. This is mainly due to the picking distribution of full pallets.
- The number of S/R cycles per rack is highly variable, this can to same degree be explained by their proximity to the I/O area. However, it is unclear why rack 27 is so much more popular than racks with similar attributes.
- For each rack, the majority of the picks are from the bays closest to the I/O area. However, the number of S/R cycles per bay is highly variable, and there are several bays close to the I/O area with a surprisingly low picking frequency. In addition, some bays with a majority of A zone locations have the lowest number of S/R cycles
- The total amount of S/R cycles per shelf, shows that shelves 2 to 6 has an even distribution of picks and that there is a decrease for shelves 7 and 8. However, the results indicates that the lower shelves are not the most popular shelves in the picking process as shelf 2 has fewer picks than shelf 3 and 4.

4.3.3 Demand Patterns

To understand the variations in demand at Leman, several demand pattern analyses were performed. The demand patterns are important for understanding when the reshuffling would be most beneficial or necessary to perform.

First, the weekly number of S/R cycles for 2019, 2020 and 2021 were plotted, see Figure 4.16. This gives an overview of the main demand variations during a year. The figure shows that a demand pattern definitely exists, as the same increases and decreases in the number of S/R cycles reoccur in the same periods in each of the illustrated years.

There are several peaks and a high degree of fluctuations in the demand. For the year 2021 there is a difference of approximately 1500 S/R cycles between the highest peak and lowest point. The fluctuations in the demand may be accounted for by seasonality. The Easter holiday fell to week 16, 15 and 13, for the years 2019, 2020 and 2021 respectively. The figure describes a high demand just before the Easter holiday and then a low demand during the Easter holiday. There is also an increase in the demand before Christmas, and a low demand during the Christmas holidays. This is in line with how the management at Leman describes the demand at Leman prior to both Christmas and Easter.

Figure 4.16 also illustrates a general increase in demand from 2019 and 2020 to 2021. This is in line with information from the warehouse manager about Leman's growth the past time, and their generally increasing demand. This is also one of the reasons why the warehouse facility have been expanded the last year, so that more pallets can be stored and handled. This indicates that the scale of Leman's warehouse is expanding.

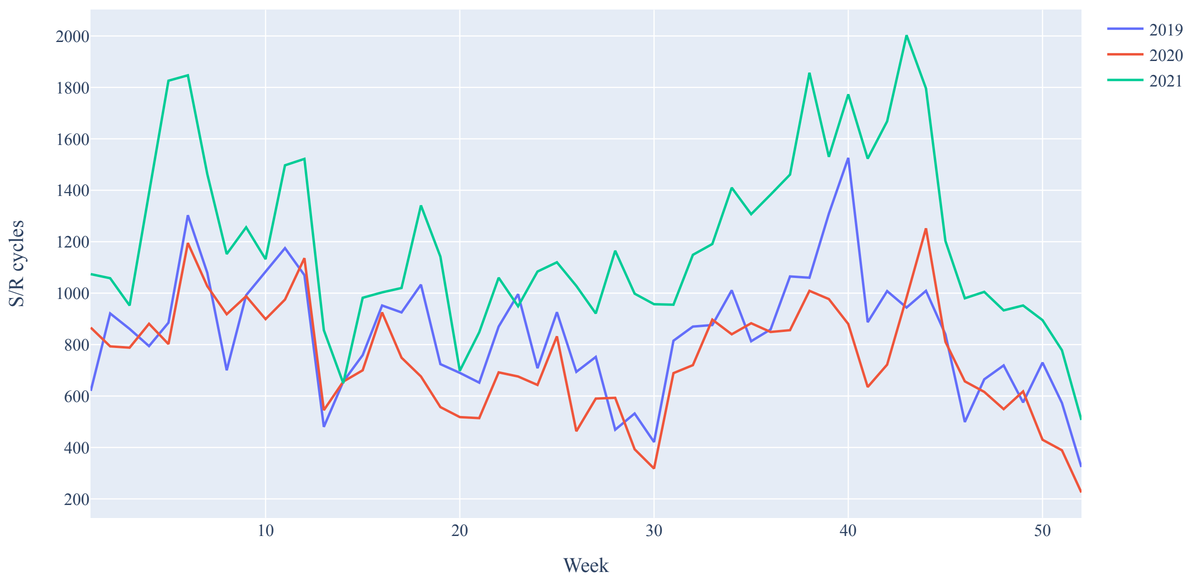


Figure 4.16: The total amount of S/R cycles per week in 2019, 2020 and 2021.

The most picked SKUs along with their name and article numbers are shown in Table 4.12. The results show that even amongst the six most frequently picked SKUs, the demand is varying. The most popular product, *112442*, is more than twice as popular as the sixth most popular product, *112493*. Note also that, compared to the total number of S/R cycles in 2021, *112442* only accounts for 3 % of the S/R cycles. In total the six most popular SKUs can account for 13 % of the total S/R cycles.

When it comes to the most frequently picked SKUs for the previous years, *112488*, *112442*, *112487*, *112493* and *112848* were included in the top 6 for 2019 as well. For 2020 *112442*, *112488*, *112487* and *112848* were in the top 6 most frequently picked SKUs. This indicates an low degree of variation for the most popular SKUs as four of the top six SKUs for 2021 are also included in the top six for the two previous years.

Article no.	**S/R cycles in 2021**
112442	2 141
112487	1 457
112488	1 388
112848	1 195
112514	1 104
112493	1 050

Table 4.12: The top six most frequently picked SKUs based on number of S/R cycles executed in 2021.

The S/R cycles per week for each of the top six most picked SKUs are shown in Figure 4.17. This illustrates the demand variations that Leman and other actors in the supply chain, have to adjust to. The figure describes a highly fluctuating demand pattern for the six most frequently picked SKUs. There are several peaks and bottom points, which means that the demand often experiences an increase or a decrease with a short duration. The changes in demand are probably related to seasonal demand or campaign demand, but this cannot be verified without additional information from the producer and wholesaler.

Plots showing the S/R cycles per week for the top six most frequently picked SKUs are included to illustrate that basing the storage location assignment solely on the most frequently picked products is not the best solution. This is because there are great variations in the demand for these products through the year.

Comparing the plots for each of the six most frequently picked products indicates that each SKU has its own demand pattern. This information can be used as an input to the decision making process related to reshuffling. For example the figure shows an increase in demand just before week 20, for *112487*, and a decrease in demand at the same time for *112514*.

Another demand pattern to investigate is the demand per day of the week. In Table 4.13, the total number of S/R cycles for each weekday in 2019, 2020, and 2021 is summarized. The table clearly shows that on average Monday is the least busy weekday for all of the analyzed years. Tuesday is, on average, the busiest day each year followed by Wednesday (The exception is 2020, where Wednesday and Friday share second place).

To compare the activity level for each month, the total number of S/R cycles for each weekday for every month was plotted in Figure 4.18. The results in this figure reveals several interesting aspects of Leman's demand profile, which influences how they should operate.

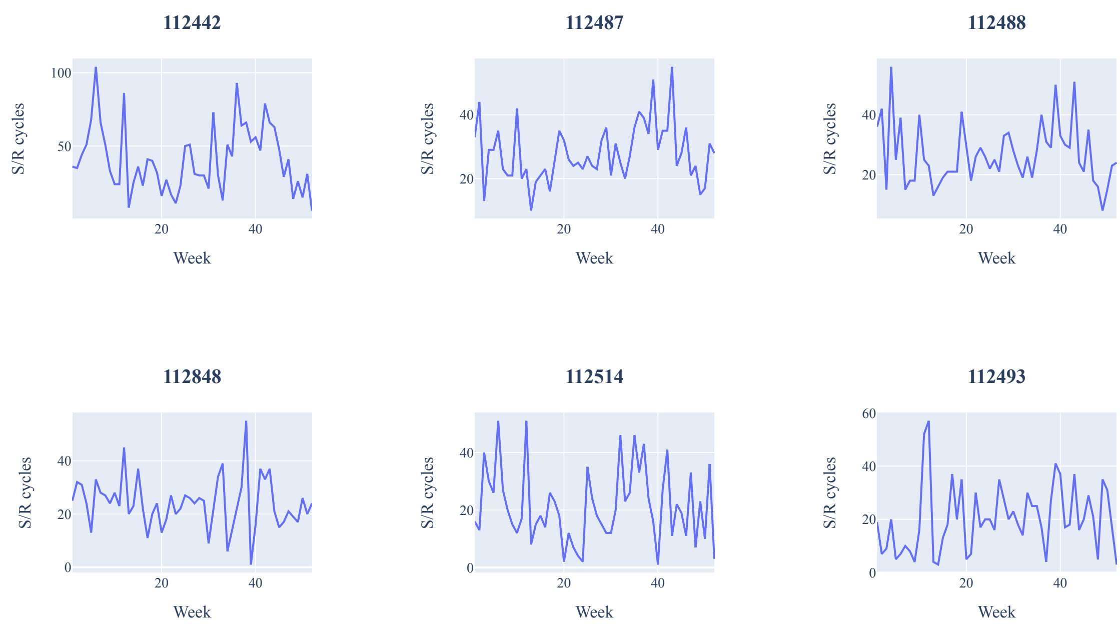


Figure 4.17: Plots showing the S/R cycles per week for the top six most frequently picked SKUs as described in Table 4.12

Day	**% of total S/R cycles**		
	2019	**2020**	**2021**
Monday	15.6 %	15.6 %	16.0 %
Tuesday	22.0 %	21.6 %	25.0 %
Wednesday	20.7 %	21.2 %	20.1 %
Thursday	18.7 %	18.3 %	18.0 %
Friday	21.0 %	21.2 %	18.7 %
Saturday	1.6 %	1.6 %	1.8 %
Sunday	0.4 %	0.5 %	0.4 %

Table 4.13: Percentage of total number of S/R cycles per weekday in 2019, 2020, and 2021.

Firstly, note that the number of S/R cycles per weekday differs greatly for different months and is much higher for some months than other. This confirms that the demand has a high degree of fluctuation through the year, as illustrated in Figure 4.16. Note for example, that on Mondays, October has more than twice the number S/R cycles of December, on average. There is also a clear jump in the demand from July to August, and then a slight increase in September and October, before the demand drastically decreases again for November.

Secondly, the distribution of S/R cycles per weekday differs for each month. For the majority of the months, the number of S/R cycles is highest for Tuesday, which is not surprising as this is also the average distribution for the entire year. However, it is important to note that this is not the case every month. In January, the highest number of S/R cycles appears on Thursdays, followed by Fridays and Wednesdays. February has the highest number of S/R cycles on Tuesdays followed by Fridays and Wednesdays. The varying distribution of S/R cycles per weekday for different months should be taken into account when reshuffling decisions are made. However, the number of S/R cycles on Mondays is lower than the number of S/R cycles on Tuesdays for every month.

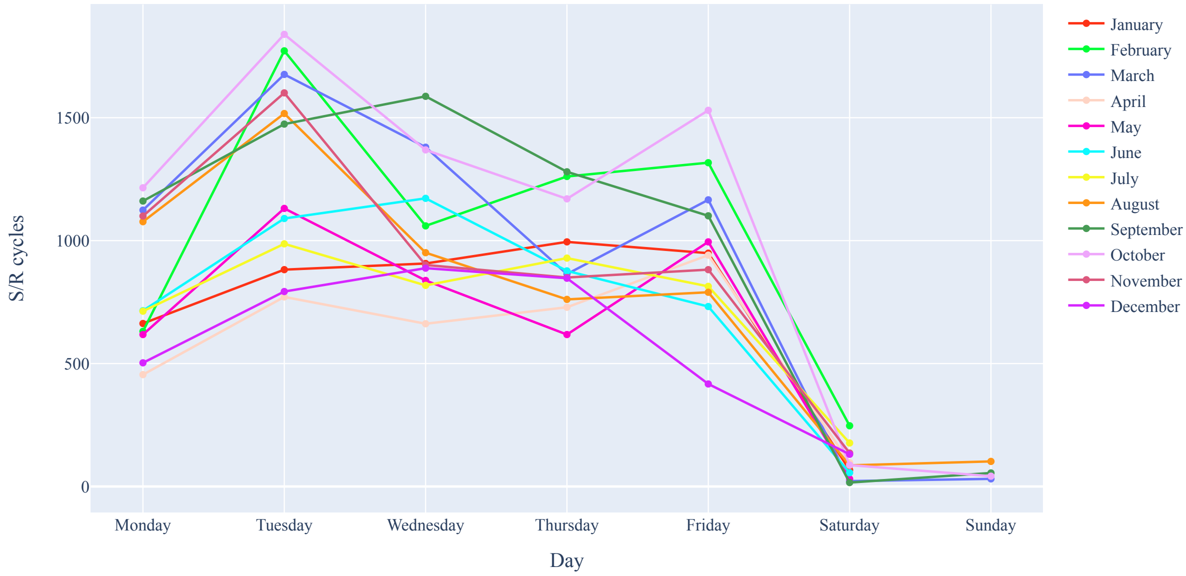


Figure 4.18: The total amount of S/R cycles per weekday for each month in 2021.

Summary of the Demand Patterns

- There is a pattern in the demand Leman experiences.
- The overall demand has increased in 2021.
- The demand can be characterized as fluctuating with several peaks and dips, both overall and for individual SKUs.
- Leman experiences seasonal demand, with a demand increase before Easter and Christmas.
- The demand per weekday for different months varies, but there are still some clear patterns such as the fact that Tuesdays are more busy than Mondays.

4.4 Reshuffling Analysis

The analysis of the current situation at Leman in Section 4.3 shows that there are several challenges and improvement areas with their order picking process. One possibility for handling some of these issues can be to implement goods reshuffling. Updating the physical locations of the goods can reduce the travel time for the order picking process, and thus, the order throughput time. To investigate how reshuffling can be implemented at Leman and the possible effects of reshuffling, several reshuffling scenarios were made, and travel time calculations were performed. The reshuffling method investigated was manual reshuffling during idle time, and the analyses were performed separately for the full pallet area and for the carton picking area. This section first describes the reshuffling method and its constraints and assumptions, then presents the results from the analyses of the method. Finally, the method is compared for the two different picking areas.

4.4.1 Method

There are several different opportunities for implementation of reshuffling at Leman. The focus could be either on full pallet picking, on carton picking, or on both. The reshuffling can be performed either during idle time or during the working time. Due to the limitations of Leman's WMS and the types of data currently available, the reshuffling method chosen for further investigation concerns reshuffling during idle time. Additionally, using idle time for reshuffling is less complex than continuous reshuffling, and the analysis of this method can therefore generate better results. Since there are two types of order picking processes at Leman (full pallets and mixed pallets), the reshuffling method was analyzed for both the carton picking area and for the full pallet area.

To analyze the performance of the chosen reshuffling method, travel time estimations were made. Comparing the total travel time for different reshuffling scenarios and order picking scenarios can give an indication of the performance of different solutions, as the travel time is one of the most time-consuming warehouse activities.

For all travel time calculations and reshuffling scenarios, the same assumptions were made. The racks included in the analyses are the most popular racks (26-34) in the warehouse, as identified in the analysis of the current situation (Figure 4.11). For simplification, all calculations are zone-based instead of single storage location based. Thus, the average distances to each of the zones are used in the calculations. The assumptions are made based on either information from Leman, information from previous work on Leman, or on observations. All numerical assumptions used in the calculations are summarized in Table 4.14.

Parameter	Assumed value
Bay width	0.9 m
Shelf height	1.9 m
Rack length	59.5 m
Average distance to zone A	5.4 m
Average distance to zone B	27.9 m
Average distance to zone C	52.2 m
Forklift horizontal velocity	2 m/s
Forklift vertical velocity	0.4 m/s
Average distance from I/O point to first bay	10 m

Table 4.14: An overview of the assumptions made for the travel time calculations.

The travel time calculations for the different reshuffling scenarios were performed separately for the full pallet area and for the carton picking area. The reason for separating the two is the many differences between the picking processes in the areas. Also, the WMS distinguishes between the to processes in the transaction data which are used in the analyses. The main difference is that the carton picking only takes place at the ground level, while the full pallet picking occurs at shelf number 2 to 7. Thus, for full pallet picking, the travel time is a combination of horizontal and vertical travel time, while for carton picking, the travel time is only horizontal. Additionally, the ABC classification zones differs between each level and between the different racks. For each area, a definition of an S/R cycle and a reshuffling cycle was made, which was later used in the analyses. The method for each area with its assumptions and definitions is described below.

Full Pallet Area

The full pallet picking takes place in the shelves 2 to 7, but as identified in the picking pattern analysis, most of the picking occurs in shelf 2, 3, 4, 5 and 6. Shelf 2-6 will therefore be the ones included in the analysis. The locations of the zones A, B and C varies between the different shelves, as shown in Figure 4.19. Thus, the zones for the different shelves have different travel distances, and the travel time must be calculated separately for each shelf. Also, the vertical travel time (the time it takes to lift a pallet up/down to/from the relevant shelf) must be included when analyzing the full pallet area due to the differences in heights of the shelves and the relatively slow vertical forklift speed. To avoid including too many different scenarios, shelf number 2, 4 and 6 were chosen for the analysis. These are the bottom, middle and top shelves of the most popular shelves for the full pallet picking, and the results should therefore be representative for all full pallet picking shelves. Note that shelf number 2 does not contain the zone C.

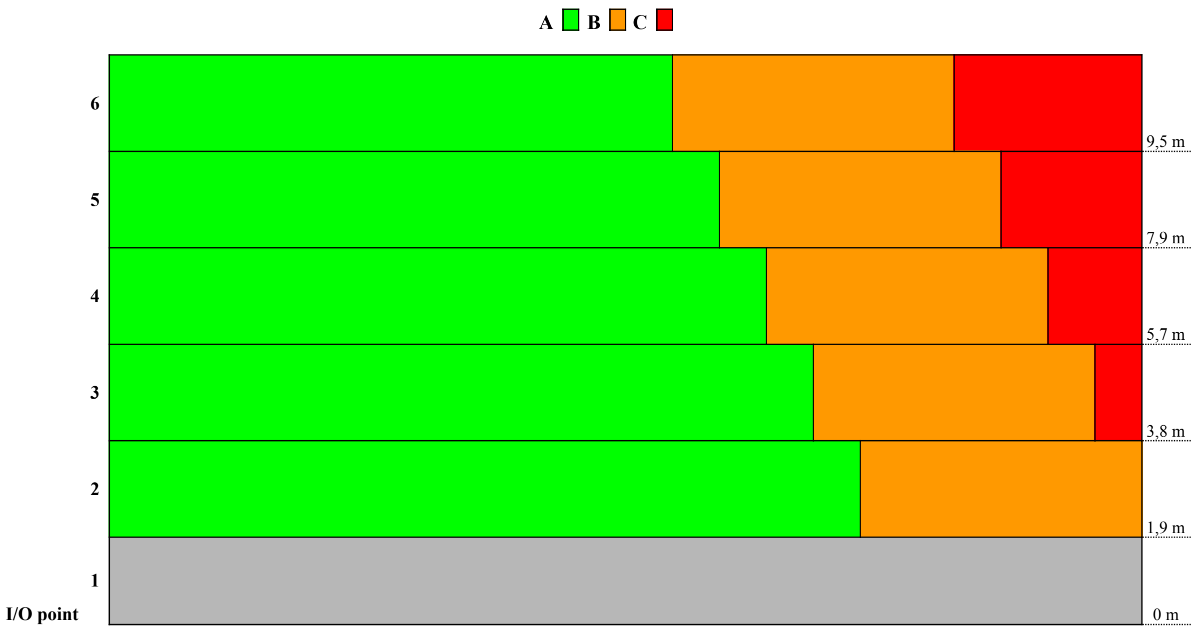


Figure 4.19: The zones A, B and C for the relevant shelves for reshuffling in the full pallet area. The figure shows one arbitrary rack as seen from the side with the corresponding zones (the zones are similar for all relevant racks). The heights in the bottom of each shelf are shown to the right of the figure. Shelf number 1 is shown in gray because it is not relevant for the analyses in this area.

For the full pallet picking, an S/R cycle includes the picking of one full pallet from a specific shelf. A reshuffling cycle includes reshuffling a specific amount of pallets from one shelf in zone B or C to a new shelf in zone A. The S/R cycle and reshuffling cycle for the full pallet area are defined in Table 4.15.

S/R cycle	Reshuffling cycle
1. Start at the I/O point.	1. Start at the I/O point.
2. Travel to the relevant storage zone.	2. Travel to the relevant zone to reshuffle from (B or C).
3. Lift one pallet down from the relevant shelf.	3. Lift one pallet down from the relevant shelf.
4. Travel back to the I/O point.	4. Move the pallet to zone A and lift it up to an available storage location in the relevant shelf.
	5. Repeat step 2-4 until all the desired pallets are reshuffled.
	6. Travel back to the I/O point.

Table 4.15: Definition of an S/R cycle and a reshuffling cycle for the full pallet area.

Carton Picking Area

The carton picking takes place in the ground level (shelf number 1) and the travel time is therefore only horizontal. Additionally, the location of the zones A, B, and C on the ground level varies between the different racks, as shown in Figure 4.20. Thus, each rack was analyzed separately. Note that rack number 27 and 31 does not contain the zone C.

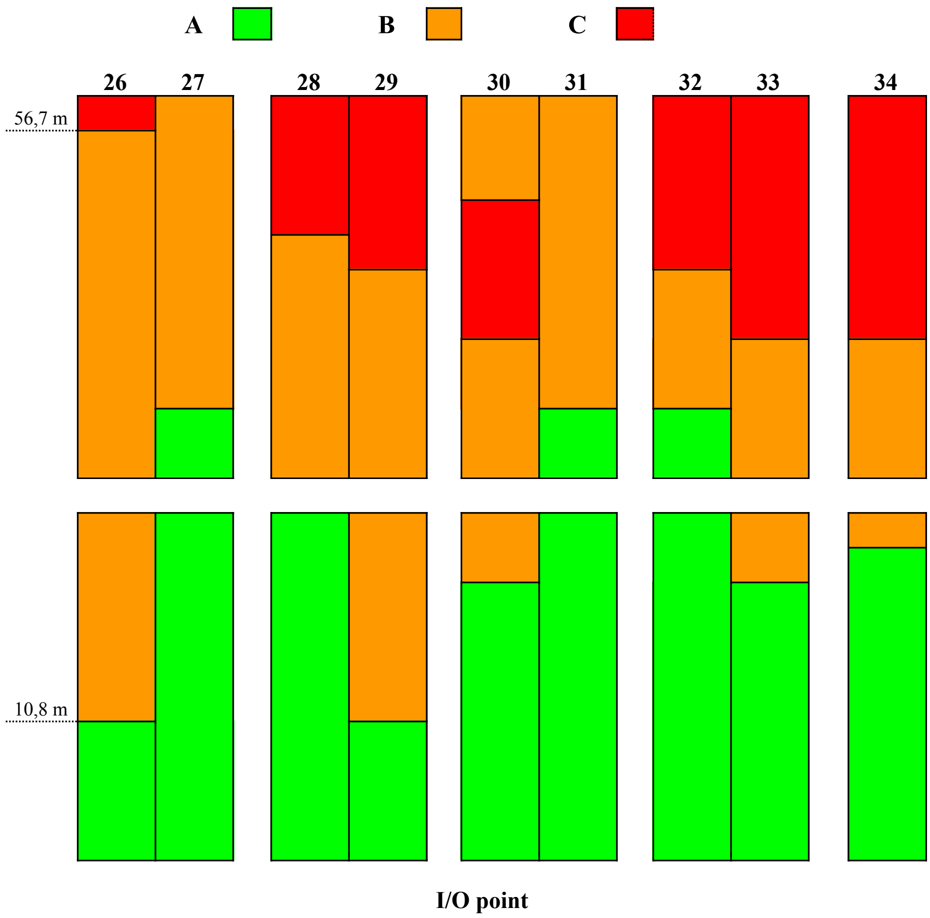


Figure 4.20: The zones A, B and C for the relevant racks for reshuffling in the carton picking area. The figure shows rack 26-34 at the ground level (shelf 1) as seen from above. To the left, the distances from the beginning of zone A to the beginning of zone B and C for rack 26 is shown to illustrate the lengths.

For the carton picking, an S/R cycle includes the picking of one carton layer instead of one full pallet. The reshuffling cycle for the carton picking area is identical to the reshuffling cycle in the full pallet area, except that there is no lifting due to everything occurring at the ground level. The S/R cycle and reshuffling cycle for the carton picking area are defined in Table 4.16.

4.4.2 Results

For each picking area, several different scenarios were studied in order to cover different aspects of the reshuffling method. For all scenarios, it is assumed that there are always enough available storage locations to perform the reshuffling. This section shows the results of the following calculations:

1. Calculation of the travel time for different picking scenarios.
2. Calculation the travel time for different reshuffling scenarios corresponding to the picking scenarios.

S/R cycle	**Reshuffling cycle**
1. Start at the I/O point. 2. Travel to the relevant storage zone . 3. Pick one layer of cartons. 4. Travel back to the I/O point.	1. Start at the I/O point. 2. Travel to the relevant zone to reshuffle from (B or C) in the relevant rack. 3. Pick one pallet. 4. Move the pallet to zone A in the same rack and place it on an available storage location. 5. Repeat step 2-4 until all the desired pallets are reshuffled. 6. Travel back to the I/O point.

Table 4.16: Definition of an S/R cycle and a reshuffling cycle for the carton picking area.

3. Calculation of the travel time saved in the order picking process by implementing reshuffling during idle time for the different corresponding picking scenarios.

The calculations were made separately for each scenario in each of the two picking areas. The results for the areas are described below, followed by a comparison of the two. All travel time estimates in the tables are given in minutes.

Full Pallet Area

First, the travel time for different full pallet picking scenarios were calculated. Each scenario focused on picking 50 full pallets, corresponding to 50 S/R cycles. The calculations were performed for each shelf and for each zone. The travel time estimates are shown in Table 4.17.

Picking scenario	**Shelf**	**Total horizontal travel time**	**Total vertical travel time**	**Total travel time**
Pick 50 pallets from zone A	2	26.33	7.92	34.25
	4	24.08	23.75	47.83
	6	21.83	39.58	61.41
Pick 50 pallets from zone B	2	51.02	7.92	58.94
	4	46.58	23.75	70.33
	6	42.08	39.58	81.66
Pick 50 pallets from zone C	4	55.58	23.75	79.33
	6	53.33	39.58	92.01

Table 4.17: Travel time estimations for picking 50 full pallets from the different zones A, B, and C in shelves number 2, 4, and 6.

Next, the travel time for different reshuffling scenarios were calculated. These scenarios also focus on 50 pallets in order to compare with the picking scenarios. Here, the travel time is calculated for reshuffling from zone B to zone A, and from zone C to zone A, for all possible shelf combinations of shelf 2, 4, and 6. The travel time estimates are shown in Table 4.18.

Reshuffling cycle	**Original shelf** (zone B/C)	**New shelf** (zone A)	**Total horizontal travel time**	**Total vertical travel time**	**Total travel time**
Reshuffle 50 pallets from zone B to zone A	2	2	25.77	15.84	41.61
		4	28.02	31.67	59.69
		6	30.27	47.50	77.77
	4	2	21.18	31.67	52.85
		4	23.43	47.50	70.93
		6	25.68	63.33	89.01
	6	2	16.59	47.50	64.09
		4	18.84	63.33	82.17
		6	21.09	79.16	100.25
Reshuffle 50 pallets from zone C to zone A	4	2	30.36	31.67	62.03
		4	32.61	47.50	80.11
		6	34.86	63.33	98.19
	6	2	28.07	47.50	75.57
		4	30.32	63.33	93.65
		6	32.57	79.16	111.73

Table 4.18: Travel time estimations for reshuffling 50 full pallets between shelf number 2, 4 and 6 between the different zones A, B and C.

Finally, the estimated savings in travel time were calculated. The scenarios are based on the results from Table 4.17, and compares the time saved and the percentage reduction in time by picking from zone A instead of zone B or C. The time it takes to reshuffle is not included in these time estimates, because the reshuffling is supposed to take place during idle time. The estimates are shown in Table 4.19.

Table 4.19 shows that the percentage reduction in travel time varies from 22.59 % to 62.58 %, which has a difference of 40.19 %. For zone C, it varies from - 4.19 % to 58.06 %, which has a difference of 62.25 %. These are large variations, which indicates that the chosen shelves and zones to reshuffle to and from is an important factor for the efficiency of the reshuffling. Additionally, not all reshuffling scenarios were even time saving. The calculations shows that picking from shelf 6 in zone A is actually more time consuming than picking from shelf 2 in zone B: the travel time is 2.47 minutes longer. This indicates that the storage locations are not optimal as it should in no scenarios be less time consuming to pick from zone B or C than from zone A.

The results from Table 4.19 show that the highest reduction in time appears in the scenarios where the pallets are reshuffled from a higher shelf to a lower shelf. The two scenarios with largest percentage reduction in travel time is where the pallets are picked from shelf 2 in zone A instead of shelf 6 in zone B or C: respectively 58.06 % and 62.78 %. The difference between picking from zone B vs. zone C in these scenarios is small, only 4.72 %. Similar results are found

After reshuffling scenario	**Original shelf** (zone B/C)	**New shelf** (zone A)	**Total travel time saved** (vertical + horizontal)	**Percentage reduction**
Pick from zone A instead of zone B	2	2	24.69	41.89 %
		4	11.11	18.85 %
		6	- 2.47	- 4.19 %
	4	2	36.08	51.30 %
		4	22.50	31.99 %
		6	8.92	12.68 %
	6	2	47.41	58.06 %
		4	33.83	41.43 %
		6	20.25	24.80 %
Pick from zone A instead of zone C	4	2	45.08	56.83 %
		4	31.50	39.71 %
		6	17.92	22.59 %
	6	2	57.76	62.78 %
		4	44.18	48.02 %
		6	30.60	33.26 %

Table 4.19: Total travel time saved and percentage reduction from original travel time for the different scenarios for shelf number 2 and shelf number 6. The total time saved is calculated by subtracting the total time for the picking scenarios for zone A from the total time for the picking scenarios for zone B/C. The percentage reduction is the reduction in time for picking from zone A instead of the original zone B/C.

for picking from shelf 2 in zone A instead of shelf 4 in zone B or C. This indicates that for full pallet reshuffling, the largest savings in time come from reshuffling pallets from high shelves to low shelves. This has a bigger impact on the time savings rather than if the pallets are moved from zone B vs. from zone C. This is a result of the slow vertical speed of the forklifts, and it should therefore be an important factor to consider when planning the reshuffling.

Carton Picking Area

For each rack, the travel time for different picking scenarios and reshuffling scenarios were calculated. Since one S/R cycle in the carton picking process consist of picking one layer of cartons, the picking scenarios were based on picking 50 carton layers. This corresponds to 50 S/R cycles, and the scenarios can therefore be compared to the scenarios in the full pallet area. For this analysis, it is assumed that one mixed pallet consist of 5 carton layers, meaning that picking 50 carton layers corresponds to filling 10 mixed pallets. Thus, the corresponding reshuffling scenarios were based on reshuffling 10 pallets. The travel time estimates for each rack are shown in Table 4.20 (rack 26 and 27), Table 4.21 (rack 28 and 29), Table 4.22 (rack 30 and 31), Table 4.23 (rack 32 and 33), and Table 4.24 (rack 34).

Finally, the savings in travel time and the percentage reduction from the original travel time for

Scenario (rack 26)	**Total travel time**
Pick 50 carton layers from zone C	56.71
Pick 50 carton layers from zone B	36.46
Pick 50 carton layers from zone A	12.83
Reshuffle 10 pallets from C to A	9.91
Reshuffle 10 pallets from B to A	5.45

Scenario (rack 27)	**Total travel time**
Pick 50 carton layers from zone C	N/A
Pick 50 carton layers from zone B	47.71
Pick 50 carton layers from zone A	22.96
Reshuffle 10 pallets from C to A	N/A
Reshuffle 10 pallets from B to A	5.90

Table 4.20: Travel time estimations for rack 26 and 27.

Scenario (rack 28)	**Total travel time**
Pick 50 carton layers from zone C	51.08
Pick 50 carton layers from zone B	38.71
Pick 50 carton layers from zone A	19.58
Reshuffle 10 pallets from C to A	7.32
Reshuffle 10 pallets from B to A	4.60

Scenario (rack 29)	**Total travel time**
Pick 50 carton layers from zone C	40.96
Pick 50 carton layers from zone B	26.33
Pick 50 carton layers from zone A	12.83
Reshuffle 10 pallets from C to A	6.44
Reshuffle 10 pallets from B to A	3.23

Table 4.21: Travel time estimations for rack 28 and 29.

Scenario (rack 30)	**Total travel time**
Pick 50 carton layers from zone C	49.96
Pick 50 carton layers from zone B	34.21
Pick 50 carton layers from zone A	17.33
Reshuffle 10 pallets from C to A	7.52
Reshuffle 10 pallets from B to A	4.06

Scenario (rack 31)	**Total travel time**
Pick 50 carton layers from zone C	N/A
Pick 50 carton layers from zone B	47.71
Pick 50 carton layers from zone A	22.96
Reshuffle 10 pallets from C to A	N/A
Reshuffle 10 pallets from B to A	5.90

Table 4.22: Travel time estimations for rack 30 and 31.

Scenario (rack 32)	**Total travel time**
Pick 50 carton layers from zone C	52.21
Pick 50 carton layers from zone B	42.08
Pick 50 carton layers from zone A	22.96
Reshuffle 10 pallets from C to A	6.89
Reshuffle 10 pallets from B to A	4.67

Scenario (rack 33)	**Total travel time**
Pick 50 carton layers from zone C	49.96
Pick 50 carton layers from zone B	34.21
Pick 50 carton layers from zone A	17.33
Reshuffle 10 pallets from C to A	7.52
Reshuffle 10 pallets from B to A	4.06

Table 4.23: Travel time estimations for rack 32 and 33.

Scenario (rack 34)	**Total travel time**
Pick 50 carton layers from zone C	49.96
Pick 50 carton layers from zone B	35.33
Pick 50 carton layers from zone A	18.46
Reshuffle 10 pallets from C to A	7.30
Reshuffle 10 pallets from B to A	4.08

Table 4.24: Travel time estimations for rack 34.

the different scenarios for each rack were calculated. Like in the situation with reshuffling of full pallets, the time it takes to perform the reshuffling itself is not included in these time reduction estimates, because the reshuffling should happen during idle time. All estimates are shown in Table 4.25.

As shown in the tables, the travel time for the reshuffling itself is very short because only 10 pallets are needed to move in the reshuffling cycle to match 50 S/R cycles of picking. For the carton picking area, it takes on average 4.66 minutes to reshuffle 10 pallets from B to A, and 7.56 minutes to reshuffle 10 pallets from C to A. Thus, a short amount of idle time can produce large savings in future travel time.

The average time saved for picking 50 pallets from zone A instead of zone B is 19.50 minutes, which is a reduction of 51.23 % from the original average travel time to zone B. The average time saved for picking 50 carton layers from zone A instead of zone C is 32.69 minutes, which is a reduction of 65.34 % from the original average travel time to zone C. This shows that reshuffling from both zone B to zone A and from zone C to zone A during idle time will, on average, reduce the original travel time by more than fifty percent. However, the results indicate that the largest savings in travel time appears in the scenarios where the pallets are reshuffled from

After reshuffling scenario	Rack	Total travel time saved	Percentage reduction
Pick from zone A instead of zone B	26	23.62	64.80 %
	27	24.75	51.88 %
	28	19.13	49.41 %
	29	13.50	51.27 %
	30	16.88	49.33 %
	31	24.75	51.88 %
	32	19.13	45.45 %
	33	16.88	49.33 %
	34	16.88	47.76 %
Pick from zone A instead of zone C	26	43.88	77.37 %
	27	N/A	N/A
	28	31.50	61.66 %
	29	28.13	68.67 %
	30	32.62	65.30 %
	31	N/A	N/A
	32	29.25	56.03 %
	33	32.62	65.30 %
	34	31.50	63.05 %

Table 4.25: Total travel time saved by picking from zone A instead of zone B/C and percentage reduction from the original travel time for for the most popular racks.

zone C rather than from zone B.

The largest percentage reduction in travel time were found for rack 26. Here the reduction in travel time were 64.80 % for reshuffling from zone B, and 77.37 % for zone C. The lowest savings in travel time were found for rack 32, with a reduction of 45.45 % for reshuffling from zone B and 56.03 % for reshuffling from zone C. This means that the differences in percentage reduction for the most and least efficient reshuffling racks are 19.35 % for reshuffling from zone B, and 21.34 % for reshuffling from zone C.

Comparison

From the results of the reshuffling method for the full pallet area and the carton picking area, several differences were identified.

First of all, the variations between the least and most effective scenarios were very different between the two. For the full pallet area, the difference between the largest and and lowest reductions in travel time, after reshuffling, was 40.19 % for zone B and 62.25 % for zone C. For the carton picking area, the differences were 19.35 % for zone B and 21.34 % for zone C. This indicates that for the full pallet area, it is more important to focus on which shelves to reshuffle to and from, as this has a large impact on the travel time savings. For the carton picking area, the travel time differences between the racks are not as large as the differences between the shelves in the full pallet area, and is not as important to focus on.

One of the largest differences between the two areas is the difference in the travel time for the reshuffling itself, i.e., to perform one reshuffling cycle corresponding to a picking scenario. For both areas, the picking scenario investigated included 50 S/R cycles, corresponding to picking 50 full pallets or 50 carton layers. For the full pallet area, the travel time of the reshuffling cycles varied between 41.61 to 100.25 minutes for reshuffling from zone B, and from 62.03 to 111.71 minutes for zone C. In comparison, the travel time for the reshuffling cycles in the carton picking area varied from 3.23 to 5.90 minutes for zone B and from 6.44 to 9.91 minutes for zone C. This is a huge difference, which indicates that it is a lot more efficient to reshuffle in the carton picking area. This can partly be a result of the differences of the S/R cycle definition: for the full pallet area, 50 pallets must be included in a reshuffling cycle corresponding to 50 S/R cycles of picking. For the carton picking area, only 10 pallets must be included in the reshuffling cycle to match 50 S/R cycles of picking. Thus, the reshuffling cycle is much shorter for the carton picking area. The differences can also be a result of the vertical travel time included for the full pallet area, as the forklift has a relatively slow vertical lifting speed which lead to large time consumption.

To compare how the reshuffling method for each of the two picking areas would differ in practice, some specific examples of how the reshuffling can be executed were made. These are shown in Table 4.26 and 4.27. The tables contain several examples of how many pallets can be reshuffled during different amounts of idle time, and how much order picking time this will release. These examples are based on averages and rough calculations and should not be treated as facts or used as a conclusion for reshuffling decisions. However, they can provide some insight for which areas to focus on, and some general guidelines.

In the examples, some extra time have been added to the original travel time calculations to be more similar to the realistic reshuffling time and order picking time. As previously stated (see Table 3.2), the travel time usually accounts for about 55 % of the order picking time in a warehouse. To estimate the time it takes to reshuffle, 20 % time is added to the travel time to include extraction (and put-away) from the shelves. To estimate the total order picking time released after the reshuffling, 50 % time is added to the new travel time to include both extracting and searching. For the full pallet reshuffling examples in Table 4.26, the scenarios with largest percentage reduction in travel time are used as examples. For the carton picking reshuffling in Table 4.27, the average over all the racks for each scenario are used as examples.

Full pallet area		
Idle time available	**Reshuffling opportunity**	**Order picking time released**
50 minutes	50 pallets from B (shelf 2) to A (shelf 2)	40 minutes
1 hour	50 pallets from B (shelf 4) to A (shelf 2)	55 minutes
1 hour 15 minutes	50 pallets from C (shelf 4) to A (shelf 2)	1 hour 10 minutes
1 hour 30 minutes	50 pallets from C (shelf 6) to A (shelf 2)	1 hour 30 minutes

Table 4.26: Examples of how much time can possibly be saved by reshuffling the full pallet picking area.

Carton picking area		
Idle time available	**Reshuffling opportunity**	**Order picking time released**
6 minutes	10 pallets from B to A	30 minutes
10 minutes	10 pallets from C to A	45 minutes
30 minutes	50 pallets from B to A	2 hours 30 minutes
50 minutes	50 pallets from C to A	3 hours 45 minutes

Table 4.27: Examples of how much time can possibly be saved by reshuffling the carton picking area.

These examples clearly indicate that reshuffling in the carton picking area is the most beneficial solution. As little as 6 minutes of idle time used for reshuffling in the carton picking area can release about 30 minutes of order picking time. For the carton picking area in general, small amounts of idle time spent on reshuffling can lead to large savings in the order picking time. For the full pallet area, a lot more idle time have to be spent on reshuffling to release the same amounts of order picking time. Note that in these examples, it is assumed that there are always enough available storage locations in zone A to perform the reshuffling. In reality this is not the case, and it would set an upper limit for the amount of pallets that actually can be physically reshuffled.

Summary of the Reshuffling Results

- For full pallets, the percentage reduction in travel time varied between -4.19 % to 62.58 % for all scenarios tested, which indicates that the chosen shelves and zones for reshuffling is an important factor for the efficiency of the reshuffling.
- Not all reshuffling scenarios were time saving for the full pallet area. Reshuffling 50 pallets from shelf 2 in zone B to shelf 6 in zone A would increase the travel time by 2.47 minutes for the new picking scenario after reshuffling. This indicates that something is wrong with the ABC classifications.
- The results indicated that for full pallets, in general, the highest reductions in travel time appeared to be for reshuffling from a higher shelf to a lower shelf for both reshuffling from zone B and zone C. This indicates that the chosen shelves to reshuffle to and from is more important than the chosen zones.
- For the carton picking area, the percentage reduction in travel time varied between 45.45 % and 77.37 % for all scenarios tested. This is a much smaller variation between the scenarios than for the full pallet area, which indicates that the chosen racks and zones to reshuffle to and from are not as important for the carton picking area.
- The largest differences in the two areas were found between the travel time for one reshuffling cycle corresponding to the picking scenario of 50 S/R cycles. For the full pallet area, one reshuffling cycle had a travel time that varied between 41.61 to 111.25 minutes, while for the carton picking area, it varied between 3.23 to 9.91 minutes. This indicates that the carton picking area is more efficient for reshuffling.
- The practical examples made for comparison of the two areas showed that smaller amounts of idle time produced larger amounts of savings in future order picking time for the carton

picking area than for the full pallet area. This also supports that reshuffling in the carton picking area is the most beneficial solution.

4.5 Proposals

In this section, several improvement suggestions based on the analyses performed in the case study are provided. The aim of these proposals is to improve the order picking process at Leman through the use of goods reshuffling. Because the implementation of reshuffling is a compound problem with many factors affecting it, the proposals are based on both the analysis of the current situation (Section 4.3) and the reshuffling analysis (Section 4.4). The proposals are divided into four categories, as follows:

1. Taking Advantage of the Idle Time

First of all, the analyses in this study are based on reshuffling during idle time. Thus, a general recommendation is for Leman to take advantage of their idle time and use it for reshuffling.

The problems related to transportation logistics and order congestion identified in the analysis of the current situation seems to be one of the main causes to idle time at Leman. The problems gets bigger with increasing demand, and creates both more idle time and more over-time for Leman. Here, reshuffling could be useful for minimizing the over-time. This can be done by taking advantage of the idle time, and use this time for reshuffling the relevant goods. If the relevant goods for future orders are moved to storage locations with shorter travel distances, this would reduce the order picking time, and thus, it can reduce the over-time. For manually operated warehouses labor is the highest cost, as previously stated. Thus, if Leman took advantage of idle time caused by order congestion and thus reducing over-time work, this can decrease the labor costs. This suggestion also applies to lower-activity periods with more idle time.

2. Understanding the Picking Patterns

Understanding the picking patterns is important for the reshuffling decision process to ensure having all the necessary information for deciding where to reshuffle goods to and from. Thus, it is proposed that Leman should examine, analyze and monitor the picking process to fully understand the picking pattern they experience. From the picking pattern analysis in this study, it was found that some of the racks experienced more activity than others. Thus, it is proposed that Leman should take more advantage of the A-zones in the racks with lower activity levels. This can be done by reshuffling relevant goods from the zones B and C in the higher activity racks, to zone A in the lower activity racks. This way, a larger part of the relevant goods will be located in zone A and the total travel time will be reduced.

Additionally, before implementing reshuffling, it is recommended that Leman's storage policy is investigated and updated. This is because it was found some unfortunate zone locations during the analyses. For instance, the estimated average travel time to shelf 2 in zone B were shorter than the estimated average travel time to shelf 6 in zone A. This is unfortunate, as the A zones should always provide a shorter order picking time than the B zones. For the reshuffling to be efficient it is therefore important to first optimize the storage policy.

3. Understanding the Demand Patterns

Understanding the demand patterns is also important in relation to reshuffling, so that Leman can make well informed decisions on which items to reshuffle and when to perform the reshuffling based on the variations in demand. Therefore, it is proposed that Leman should examine, analyze and monitor the demand to fully understand the demand pattern they experience. If the demand pattern at Leman continues to have clear demand peaks as the analysis of the current situation showed, it is proposed that Leman reshuffles goods in the warehouse before the demand peaks to reduce the order throughput time when the demand is high. This can be done on both a large scale and small scale. Thus, it is proposed that Leman could reshuffle goods before the demand increase before Easter and Christmas and that they prioritize reshuffling on Mondays and other weekdays with lower activity levels.

As previously described, Leman has information about the orders to be picked at least one day in advance. Thus, to identify which items to reshuffle, Leman should check the orders once they are received, and investigate the locations of the goods included in the orders. If any of the relevant goods have unfortunate storage locations with long travel distances, these should be reshuffled if any idle time occurs before the orders are picked. This can, as shown in the reshuffling analysis, save a lot of time.

Another way to decide which goods to reshuffle can be by looking at previous demand patterns to identify the most popular products, and thus, focus the reshuffling on these. As the analysis of the current situation showed, some of the same SKUs have been the most picked SKUs over the last three years. These also showed large variations in demand during a year. They should therefore be in focus for the reshuffling to make sure that their storage locations are matching the demand variations.

For Leman to fully understand the demand patterns they are subjected to, it is proposed that the information flow between Leman and Brynild is investigated to identify what information is currently communicated and what information should be communicated. As identified in this study, Leman currently receives predicted sales reports from Brynild. Even though these reports could not be used for determining the order types, they have other functions. For instance, they can be applied for determining the ABC classifications for each period, which again can be used for deciding which SKUs to reshuffle. However, these reports were not always very accurate. More accurate forecasts would improve the ABC classifications, and thus, increase the efficiency of the reshuffling. Thus, improving the information flow in the supply chain should be prioritized before implementing reshuffling.

4. Reshuffling Method

Based on the analysis of the reshuffling method, several guidelines for how to perform the reshuffling were identified. First of all, it is recommended that the carton picking area should be the main focus for the reshuffling. The reshuffling analysis showed that the time it takes to reshuffle in this area is very short compared to the savings in future order picking time. For instance, 10 minutes of idle time spent on reshuffling can possibly release about 45 minutes of future order picking time. In comparison, for full pallets, the time spent on reshuffling is as least as long as the order picking time saved, which is a lot less efficient.

For the reshuffling in the carton picking area, the distribution of the percentage reduction in travel time was quite evenly distributed over the racks. This indicates that which racks to perform the reshuffling in is not very important. Thus, it is recommended that Leman uses the demand pattern analysis for determining which SKUs to reshuffle rather than focusing on specific racks.

If there are no possibilities for reshuffling in the carton picking area, it is proposed that Leman should reshuffle in the full pallet area. As mentioned, the reshuffling process is a lot more time consuming in this area, but if Leman has enough available idle time, it can possibly release a lot of future order picking time. For reshuffling in the full pallet area, it is recommended that which shelves to reshuffle to and from is carefully considered. The reshuffling analysis indicated that it is much more efficient to reshuffle from higher shelves to lower shelves, rather than the opposite, as this will produce the largest difference in saved order picking time. Thus, it is recommended that Leman focus on reshuffling pallets from high shelves to the lowest available shelves when reshuffling in the full pallet area.

Summary of the Proposals

A summary of the proposals for each category is shown in Table 4.28.

4.6 Discussion

The case study has shown that Leman is a fairly typical provider of warehousing services in the FMCG sector. Firstly, Leman is a 3PL provider and it is common in the FMCG industry to have such companies handle warehousing. Secondly, Leman experiences a fluctuating demand, which is a characteristic of the sector. Thirdly, Leman is experiencing an overall increase in demand for the services they provide, which is in tact with the experienced growth of the 3PL sector. However, there is one a-typical element of Leman as a 3PL provider. While it is common for a 3PL provider to have multiple clients, as Leman has, it is not common for one client to be so much bigger than all the rest, as is the case for Leman with Brynild.

The findings from the case study show that Leman faces several challenges. Many of these challenges can be resolved through the use of a dynamic storage policy incorporating the reshuffling of goods. However, not all the challenges faced by Leman can be solved through the proposals suggested in this study. This section discusses other solutions that Leman could implement, both relating to reshuffling and other improvement areas.

4.6.1 Reshuffling in Other Areas

This study focuses on reshuffling the full pallet picking area and the carton picking area. However, Leman has improvement areas that can possibly be solved by reshuffling in other areas. As discussed in Challenge 2 in Section 4.3.1, Leman experiences inefficiency caused by fast moving SKUs. This is an issue that could be improved by implementing reshuffling in the I/O area. Outbound orders in the near future should be taken into account when the storage locations are assigned to incoming SKUs. This solution would allow for incoming SKUs, that are to be picked shortly after put-away, to be reshuffled directly to the outbound area. If this suggestion is not

	Proposals
1	• In general, take advantage of the idle time and use it for reshuffling.
2	• Examine, analyze, and monitor the picking process to fully understand the picking patters. • Even out the picking pattern distribution over the racks by reshuffling goods from zone B or C in high activity racks to zone A in low activity racks. • Investigate and update the storage policy to ensure that the zone locations are optimized.
3	• Examine, analyze, and monitor the demand variations to fully understand the demand patterns. • Focus on reshuffling before high peaks in demand, especially: – Low activity periods before the high demand increase before Christmas and Easter. – Weekdays with lower activity levels, especially Mondays. • Use the incoming orders to identify which SKUs to reshuffle. • Focus on the most popular SKUs, as they have highly variable demand. • The information flow between Leman and Brynild should be investigated to provide more accurate forecasts which will simplify the decision process for the reshuffling.
4	• The main focus area of reshuffling should be the carton picking area. • Focus on which SKUs to reshuffle rather than which racks. • If reshuffling in the carton picking area is not possible, reshuffle in the full pallet area. Here, carefully consider which shelves to reshuffle to and from. In general, reshuffle from higher shelves to lower shelves.

Table 4.28: Summary of the proposals for improving the order picking process through reshuffling.

plausible, the relevant SKUs could be assigned to storage locations close to the I/O area. It is suggested that Leman investigate this issue further to find the most desirable solution. Another option that Leman should investigate is the possible benefits of reshuffling goods near expiry to locations that are closer to the I/O area. This could solve Challenge 4 presented in Section 4.3.1.

4.6.2 Continuous Reshuffling

Reshuffling can be performed during idle time or continuously during normal operations. This study finds that Leman should focus on reshuffling during idle time, but there are possibilities for performing continuous reshuffling as well. This solution should be investigated to consider the possible benefits.

The analyses of this study show that the reshuffling of full pallets is more time consuming than the time saved by the reshuffling activity. Thus, for continuous full pallet reshuffling to beneficial, some adjustments must be made. A suggestion is to have the operators move two unit loads at the same time, to decrease the travel time. However, as described in Challenge 1, Section 4.3.1, the WMS does not comply with two unit loads being transported at the same time. The functional description of the WMS shows no configuration that will allow for the possibility of transporting multiple unit-loads at the same time. Thus, Leman must investigate and consider the trade-off between the decreased travel time when driving multiple unit loads at the same time versus the discrepancies caused by this.

Challenge 5 in Section 4.3.1 describes issues related to the replenishment of the carton picking area for mixed pallet picking. There are several possible solutions that can reduce the order throughput time for this issue. Even though it is stated that the scale of Leman's warehouse does not require an operator to be solely assigned to the replenishment of the picking area, this is a solution that should be investigated. This is a solution that was also suggested by the IT manager. The scale of Leman's warehouse is increasing and having an operator solely assigned to replenishment of the carton picking area, or reshuffling of goods, could prove beneficial.

4.6.3 Communication and Systematization

The lack of communication and systematization within the supply chain causes several challenges for Leman. This is problematic as it causes Leman to be reliant on a few employees as well as uncertainty and inefficiency. In addition, as the scale of Leman's business show a trend of increasing, and implementing a reshuffling activity would make their operations even more complex, these challenges can increase in impact.

This study proposes that Leman takes advantage of their idle time. However, it is difficult to predict when this idle time occurs. One of the reasons for this is highlighted in Challenge 7, Section 4.3.1. This issue, related to transportation logistics, should be investigated and discussed with Brynild. Brynild delivers goods to Leman from several factories (their own factory in Fredrikstad and 5-8 foreign factories). There are many different people involved in the transportation of goods, and Brynild might have better communication with them than Leman. A possibility could be to use some sort of positioning system for tracking of the trucks. This way, Leman could receive real-time data with information about the position of the trucks and get a better overview of the timing of arrival and departure of goods. In general, there should be stricter rules for the time slots assigned to the trucks. Brynild and Leman could also set up a schedule for the truck moving continuously between the Fredrikstad factory and Leman's warehouse. This way, Leman would have a better overview of the timing of the goods arrivals and could plan the daily activities more accurately. The schedule could for instance have a time horizon of one week, and be sent to Leman at the beginning of every week. This solution could also be a step towards solving the issues related to order congestion described in Challenge 8, Section 4.3.1.

Leman separates the storage area into a full pallet picking area and a carton picking area for mixed pallet picking. As this study proposes that Leman prioritizes reshuffling in the carton picking area, a knowledge of the order types would be beneficial. Currently, the forecasts Leman receives from Brynild does not specify order type, as described in Challenge 10 in Section 4.3.1. To forecast the specific order types, Leman could use their historic activity data (KPI reports and transaction data from the WMS) to make their own forecasts. Their historical activity data includes the order types, and by combining this with Brynild's sales forecast, the predictions can possibly become more accurate. The supply chain director at Brynild states that Brynild needs a transition model to calculate the order forecasts into useful information for Leman. As the order picking is one of the most time-consuming activities, more accurate predictions in this area could have a significant effect on the warehouse performance. This is something that could be further investigated in the future.

It is also recommended that guidelines for when to comply with the principles, discussed in Challenge 4 in Section 4.3.1, and when to ignore them are formalized. This should be discussed with Brynild. For example, if the chance of expiry is next to zero, as for many fast-moving SKUs, the FEFO principle might be ignored. In addition, Leman should analyze how the compliance of the two principles affects the order throughput time.

A systematization of several areas at Leman could be beneficial to improve the accuracy of storage location assignment, optimize the reshuffling activity and to pass on important information in the future. Information about all the operators that affects their working speed and efficiency should be written down and systematized. This involves the different picking speeds, their core competence and expertise area, and their preferred activities. Assigning tasks the operators are skilled with can increase their motivation, and thus, their working efficiency. The average time consumed during the different operations should also be measured for each operator. This way the total amount of time the different activities will take to finish will be easier to estimate and plan. Many WMSs have functions for this type of measurement, and if possible, Leman should investigate these solutions.

Chapter 5

Discussion

The purpose of this chapter is to connect the findings from the literature study and the case study to discuss the research questions in the thesis. The chapter is split in three sections corresponding to each of the three research questions.

5.1 Dynamic Storage Location Assignment and Reshuffling

RQ1: *What are the potential benefits of dynamic storage location assignment and reshuffling?*

5.1.1 Benefits of Dynamic Storage Location Assignment

Dynamic storage location assignment concerns all storage policies that include having dynamic storage locations, unlike static storage assignment which concerns fixed storage locations. The purpose of having dynamic storage locations rather than static is to be able to strategically update the locations based on volume and demand in order to increase the warehouse efficiency. Even though the largest part of literature concerning storage location assignment have focused on static solutions, there are several benefits of implementing dynamic storage location assignment.

The literature reveals that the main benefit of implementing a dynamic storage policy is that it can lead to large savings in travel time, and thus, increase the efficiency of the order picking process. Order picking is commonly the most time-consuming warehouse activity, accounting for about 55 % of the total time spent on warehouse operations. As travel time is what consumes most of the order picking time, the travel time is an important factor for the total warehouse performance and it should therefore be reduced as much as possible. Warehouses are often large facilities with great distances between different storage locations, so the locations of the goods therefore have a big influence on the total amount of time it will take to pick the goods. A dynamic storage policy aims towards strategically placing the goods as close to the I/O area as possible based on demand and volume. Thus, when the travel distances are as short as possible, the travel time will also be as short as possible, and the order picking efficiency will improve.

The reduction in travel time from implementing a dynamic storage policy is especially beneficial for warehouses with large variations in demand and volume. These types of warehouses are commonly found in the FMCG industry. FMCG are defined as fast-moving products produced in large volumes, and FMCG supply chains are generally characterized as having strong demand with large variations. Thus, the warehouses in the FMCG industry can take advantage of strategically planning their storage locations based on volume and demand variations.

The benefits from reducing the travel time are also very useful for 3PL warehouses in general. The amount of companies outsourcing their logistics activities have increased over the past few decades, which has lead to a massive growth in the 3PL industry. This has increased the competition in the industry, which means that the 3PL providers must differentiate themselves by creating innovation and optimizing their efficiency. One way to do this for a 3PL warehouse is to implement a dynamic storage policy, because it could make the warehouse more efficient and increase the warehouse performance. This could give the 3PL warehouse a competitive advantage.

However, implementing a dynamic storage policy can also lead to several challenges. Dynamic storage policies are in general more complex than static solutions, and there are many factors to consider. Since the locations are dynamic, they must be updated regularly, which can be time- and resource-consuming. The locations should be updated based on demand and volume, and the process does therefore require accurate data to support the decisions. This can sometimes be a challenge, especially for 3PL warehouses, as identified in the literature. 3PL providers often have several clients which can lead to challenges with communicating and integrating all of them with their own activities and receive the necessary forecasts and relevant data. This challenge was also identified in the case study: they experienced an inaccuracy in the forecasts from Brynild about incoming goods and campaigns. This lead to difficulties with planning which storage locations could be most optimal for future order picking.

5.1.2 Benefits of Reshuffling

Even less research was found on reshuffling than dynamic storage location assignment. However, some potential benefits of implementing reshuffling were identified through both the literature study and the case study.

Reshuffling is closely related to dynamic storage assignment and must be applied in combination with a dynamic storage policy. As mentioned, dynamic storage location assignment involves updating the storage locations on a regular basis, based on different factors. However, these updated storage locations often only applies to the new incoming goods in the warehouse. This means that the goods that are stored in the warehouse when the locations are updated will not be physically moved. Reshuffling concerns this physical movement of goods inside of the warehouse, and thus, it is actually an extension of dynamic storage location assignment. This indicates that it can be used to further improve the benefits that arise from a dynamic storage policy.

Like for dynamic storage assignment, the main benefit of implementing reshuffling is that it can reduce the travel time in the order picking process. This was clear from both the literature study and the case study. This is a consequence of the fact that reshuffling is an extension of dynamic storage location assignment. Since reshuffling can be used for optimizing a dynamic storage policy, this can lead to reducing the total travel time, because this is the main benefit of dynamic storage location assignment.

Another benefit of reshuffling is that it can be performed during idle time in the warehouse, and thus, improve the workload balance. One example of how such an application could improve the warehouse efficiency was identified in the case study. Leman experienced challenges with order congestion during high-activity periods, which means that the outbound area was often full and the operators could not pick any more. This resulted in idle time in the beginning of the week and over-time later in the week, which is very inconvenient for the operators. Here, reshuffling could be used during the idle time to move the relevant goods for the next orders closer to the I/O area. Thus, the travel time would be reduced later in the week, and they could possibly avoid working over-time.

It is also worth mentioning that reshuffling comes with some challenges. First of all, reshuffling is a complex problem and there are many factors to consider like how, when, and where to reshuffle. To make these decisions it is necessary to have information about future demand, and as mentioned, not every warehouse has access to this. Additionally, some warehouses can experience very little idle time, and thus, there is not enough time for performing the reshuffling.

5.2 Reshuffling Methods for Manually Operated Warehouses

RQ2: *Which methods for reshuffling are most suitable for manually operated warehouses?*

There are several methods for reshuffling goods in a warehouse. From the literature and the case study it was identified that for a reshuffling operation to be performed, three key decisions must first be made. These decisions concerns which goods are to be reshuffled, what location they should be reshuffled to, and when the reshuffling activity should take place. The combination of the reshuffling-decisions make up the method of reshuffling.

There was little literature found on reshuffling in manually operated warehouses, specifically. However, the literature reveals that reshuffling can be beneficial for a manually operated warehouse, by reducing the travel time for the order picking process, and thus, the amount of required labor. If reshuffling is to be a value adding activity, the cost of reshuffling must be less than the savings caused by reshuffling. For a manually operated warehouse, the primary reshuffling cost is labor. Thus, the decisions related to reshuffling must be viewed in the context of labor costs to evaluate the suitability.

5.2.1 Deciding Which Goods to Reshuffle

The decision of which SKUs to reshuffle is primarily based on the following:

- If the SKUs are to be picked as a full pallet or as a mixed pallet
- The demand of the SKU
- The outbound orders

The type of warehouse, their demand pattern, the frequency of outbound orders and the order type is usually what should be considered when making this decision. In addition, an important factor is the amount of time from when the specific SKUs in an outbound order is known to when it should be shipped, and the size of the order. Several papers identified in this study focus on only reshuffling pallets where cartons are to be picked for mixed pallets. In addition, the results from the case study of Leman indicated that reshuffling the carton picking area is less labor-intensive than reshuffling the full pallet area. This indicates that focusing on reshuffling pallets related to mixed pallet picking, as opposed to pallets related to full pallet picking, is more suitable for a manually operated warehouse. Note that which ever area is the focus of the reshuffling activity, the demand or the outbound orders of the relevant SKUs must be included in the decision process.

As a dynamic storage policy with reshuffling is primarily a tool used to handle fluctuating demand, the reshuffling is often based on this. However, outbound orders is a more exact measure of the expected demand and can be used in situations where the resources of the warehouse allows it. However, there must be a sufficient amount of time from the details of an outbound order is known until the order is shipped to be able to plan the reshuffling and perform it. The FMCG industry experiences a highly fluctuating demand and frequent outbound orders with a short shipping deadline. As a result, the workload and the labor cost is highly variable even on a daily basis. Thus, the decision of which goods to reshuffle can be based on the demand of the SKU, the outbound orders or a combination. Both of these options can be suitable for a manually operated warehouse, depending on the warehouse type.

5.2.2 Deciding Where to Reshuffle Goods

The choice of where to reshuffle the selected SKUs usually falls on one of the following:

- Move selected SKUs closer to the I/O area
- Move selected SKUs closer to each other

Moving selected SKUs closer to the I/O area is a choice that is popular in the reshuffling literature. As labor is the most costly resource in a manually operated warehouse, order picking is the most labor consuming operation, and the most time consuming activity in the order picking process is travel time, moving the appropriate SKUs closer to the I/O area can reduce the labor costs. The analyses completed in the case study of Leman also supports this. Thus, moving selected SKUs closer to the I/O area is a suitable reshuffling decision.

The selected SKUs can also be moved closer to each other. This is an option that is suitable for warehouses that batches orders or picks mixed pallets. In this situation, the travel time, and thus the labor cost, can be reduced by locating SKUs included in the same order close together. The choice can be based on historical demand or outbound orders.

Furthermore, the two presented options for where to reshuffle the selected SKUs can be combined. In the literature, moving selected SKUs closer together and closer to the I/O area is called the forward picking area and is a tool for reducing the travel time of mixed pallet picking. However, the literature only covers using a forward picking area for automated warehouses. For a manually operated warehouse, the labor cost of reshuffling SKUs to the forward picking area must be weighed against the savings in labor cost caused by the reshuffling activity. This can depend on the size of the warehouse and the number of each order type.

5.2.3 Deciding When to Reshuffle Goods

There are several possibilities for when to perform the reshuffling activity. The decision depends on the type of company. Reshuffling is commonly completed at the following times:

- In off-peak periods
- At the launch of a new product or a promotional campaign
- Seasonally
- Monthly
- Weekly
- Daily

This decision is also affected by the type of warehouse. The FMCG industry has a highly fluctuating demand that can vary monthly, weekly, or even daily. In addition, the industry often experiences seasonal demand and demand variations related to new products or campaigns. This leads to a demand pattern characterized by many peaks, as shown in the case study. These peaks can be long, lasting several months, or short, appearing on certain days of the week. This indicates that all the mentioned times for reshuffling can be suitable for a manually operated warehouse.

Regardless of the frequency of the reshuffling operation, a decision must also be made to whether the goods should be

- reshuffled during idle time, or
- reshuffled during the picking operation.

As labor costs are not increased if the reshuffling is performed during idle time, this is very suitable for a manually operated warehouse. In this situation, the cost of reshuffling is negligible. This will cause reshuffling to be a value adding activity as long as there are any savings in normal operations, caused by the reshuffling. However, the amount of idle time in a warehouse depends on the type of warehouse and their efficiency in operations. Warehouses in the FMCG industry are often exposed to a highly variable demand. This implies that the warehouses will have idle time in the off-peak periods and should reshuffle goods then.

Even though this study focuses on reshuffling during idle time, there are situations where reshuffling during the picking operation may prove effective for a manually operated warehouse. The case study indicates that this is primarily the case for the mixed pallet picking operation, as the reshuffling activity for full pallet picking is more time consuming than the time saved for full pallet picking.

5.3 Reshuffling Decisions Through Data Analysis

RQ3: *How can warehouse data be applied to make decisions about reshuffling in manually operated warehouses?*

As discussed in Section 5.2, the literature study and case study revealed three questions that make up the reshuffling method. These questions are: when, where, and which goods to reshuffle. In the case study, it was attempted to answer these questions through several analyses of the case company and with relevant data from the case company. Based on these results, some generalizations was made and two main data analyses for answering the three questions were identified: picking pattern analysis and demand pattern analysis. Combined, these two methods can be used to find the correct method of reshuffling for a manually operated warehouse. However, as the reshuffling method is conceptual and there are many factors that will affect exactly how a reshuffling method should be applied in a warehouse, a third method of analysis, reshuffling method analysis, is proposed. In addition it is important to evaluate the performance of the reshuffling method. This is included in the reshuffling method analysis.

5.3.1 Picking Pattern Analysis

To make decisions about where inside the warehouse the reshuffling should occur, a picking pattern analysis should be made. Mainly two types of data were identified as useful for performing this analysis:

1. Layout data
2. Transaction data

Data about the layout include maps/overviews of the warehouse layout and information about all rack numbers, shelf numbers, and bay numbers. It also contains information about distances within the warehouse and measurements of heights, lengths and widths of the shelves. This data is important for getting an overview of the area for the reshuffling to take place.

Transaction data is usually data from the warehouse's WMS. This data includes information about the registered activities in the warehouse, such as picking, put-away, movement of items, and packaging. The information can include date and time of scanning, amounts, article numbers, client numbers, and location of the transaction, to mention some. For the picking pattern analysis, the necessary transaction data involves all picking related data: what and how much is picked, when, from where.

The picking pattern analysis should in general provide insights to different aspects of the picking process and identify trends and anomalies. The goal is to identify which areas to prioritize in a reshuffling process, and what types of picking processes to focus on. A convenient way to analyze the picking patterns is by plotting the relevant data to investigate it visually. Some examples of plots to make for the picking pattern analysis:

- Plot the amount of picking for different areas in the warehouse, e.g., per rack, bay or shelf.
- If there are different types of picking processes, plot the amount of picking for each type for comparison.

Several of these analyses were performed through the case study, and they provided valuable insights to the picking patterns for the case company which were useful for the reshuffling decision making process.

5.3.2 Demand Pattern Analysis

Through the literature study and the case study it was found that reshuffling should be closely related to variations in demand to be efficient. The demand patterns can reveal when it is most beneficial to reshuffle, and which items should be in focus during different time periods. Thus, time related data can be useful. There were mainly two types of data that were identified as useful for the demand pattern analysis:

1. Forecasts
2. Transaction data

Forecast for future sales/orders can provide a lot of insight to both when the reshuffling should occur and for which products. Forecasts provides insight for when low and high activity periods occur, and to which products have a high demand at which times.

If the warehouse does not have access to forecasts or if the forecasts are inaccurate, it is also possible to use historical data such as transaction data from the WMS to identify previous demand patterns and trends. This transaction data is the same type of data as described for the picking pattern analysis, but it should be analyzed with respect to time instead of area. As for the picking pattern analysis, it can be useful to create plots for visualization of the data. Some examples of plots to make for the demand pattern analysis:

- Plot the amount of picking per time, e.g., per year, per week, per month, or per day, for different time periods.
- Plot the amount of picking per time for different SKUs.

These type of analyses were also performed through the case study, and they provided valuable insights to the demand patterns for the case company which were useful for the reshuffling decision making process.

5.3.3 Reshuffling Method Analysis

To make decisions about how to perform the reshuffling and to evaluate the performance of different reshuffling methods, the following data types can be necessary:

1. Layout data
2. Equipment data
3. Capacity data

As for the picking pattern analysis, layout data is also important for deciding the reshuffling method. For estimating the travel time, it is important to know the distances within the warehouse, and the heights, widths, and lengths of the racks, bays, and shelves. This information should therefore be included in the layout data. Equipment data is also necessary for performing travel time calculations. This data should therefore include the speed of the forklifts/trucks, both horizontal and vertical (if it is used for picking in high shelves), as well as how many pallets/cartons/etc. they can carry. Capacity data is relevant for identifying idle time and for deciding which operator should perform the reshuffling.

In this thesis, reshuffling during idle time is the main focus. To decide how to apply this method for a specific warehouse, it can be useful to perform different calculations. It was found that travel time is a good parameter to measure, as it consumes a great deal of time in a warehouse. Thus, the following calculations can be made for different scenarios:

1. Calculation of the travel time for different picking scenarios.
2. Calculation of the travel time for different reshuffling scenarios corresponding to the picking scenarios.
3. Calculation of the travel time saved by implementing reshuffling for the different corresponding picking scenarios.

The scenarios can, for instance, involve different amounts of items to pick, different areas within the warehouse, or different types of picking processes. To evaluate the results of the scenarios, the results of the calculations should be compared. The goal is to identify the most effective scenarios which will provide the largest savings in travel time during an order picking process.

These calculations were executed for several different scenarios in the case study, which focused on two areas: the full pallet area and the carton picking areas. For each area, the calculations were performed for different shelves and racks, and they all focused on reshuffling corresponding 50 S/R cycles of picking.

Chapter 6

Conclusion

The aim of this project was to investigate how manual reshuffling of goods during idle time can affect the order picking process for a 3PL provider of warehousing services. This was investigated through a literature study and a case study of a 3PL provider in the FMCG industry. The results show that reshuffling can have a positive a effect on the order picking process for a 3PL provider of warehousing services, facing uncertainty in workload and demand. The main benefit identified in this study, of both dynamic storage location assignment and reshuffling, is a decrease in travel time for the order picking process. Three main questions were identified as important to answer in order to find a suitable method for reshuffling in a manually operated warehouse. These questions involves which goods to reshuffle, where to reshuffle the relevant goods, and when to perform the reshuffling activity. How these questions are answered depends on the specific warehouse. For a warehouse to make an informed decision about the reshuffling process, picking patterns, demand patterns, and the reshuffling method should be analyzed.

The case study investigated in this thesis is a fairly typical provider of warehouse services in the FMCG industry. Thus, the findings in this study are relevant for other warehouses in this sector. Furthermore, the solutions suggested will utilize existing information and resources more efficiently and does not require any major changes in the warehouse.

The most obvious identified research gap concerns goods reshuffling in manually operated warehouses, which this thesis contributes to decreasing. However, the research gap involves both reshuffling during idle time and continuous reshuffling. For smaller 3PL warehouse providers or other small warehouses who cannot afford to implement automated order picking or reshuffling, manual reshuffling of both types can improve their order picking process. This can possibly lead to a competitive advantage and reduce costs, and this topic should therefore be further investigated. In this thesis, reshuffling during idle time was studied, but continuous reshuffling can also be beneficial, and should be further researched. In addition, there was in general found little research on dynamic storage location assignment for manually operated warehouses, which should also be investigated further.

This main limitation for this thesis is the use of one single case. The results from the case study may therefore be valid only for that particular case, which makes it difficult to generalize the findings. For future research on the topic, a multi-case study should be performed to verify the findings on manual goods reshuffling. Additionally, for the travel time estimations in the case study, several assumptions and simplifications were made which might lead to inaccurate results.

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Appendix A

Acronyms

List of all abbreviations in alphabetical order:

- **3PL** Third-Party Logistics
- **COI** Cube-per-Order Index
- **COL** Closest Open Location
- **CVRP** Capacitated Vehicle Routing Problem
- **DOS** Duration-Of-Stay
- **DSS** Dynamic Storage System
- **FEFO** First-Expiration First-Out
- **FMCG** Fast-Moving Consumer Goods
- **FMS** Flexible Manufacturing Systems
- **IFP** Inbound Full Pallets
- **I/O** Inbound/Outbound
- **KPI** Key Performance Indicator
- **MTS** Made-To-Stock
- **OFP** Outbound Full Pallets
- **OMP** Outbound Mixed Pallets
- **RFID** Radio-Frequency Identification
- **RQ** Research Question
- **RR** Ratliff and Rosenthal's picker routing algorithm
- **SKU** Stock-Keeping Unit
- **SLAP** Storage Location Assignment Problem

- **SME** Small-Medium sized Enterprise
- **S/R** Storage and Retrieval
- **TSP** Traveling Salesman Problem
- **WMS** Warehouse Management System

Appendix B

Case Study Protocol

Topic	Subtopic	Questions	Information sources
General information about the supply chain	Introduction to the case study	What are the essential factors in this supply chain? Which activities and operations do Leman perform for Brynild?	Guest lecture by Brynild's supply chain director
Challenges at Leman	Initial problem description	Which challenges are Leman currently experiencing? Which areas does Leman want to improve and why?	Previous work on Leman (specialization projects, master theses), company visit, data (KPI reports)
Order picking	Procedures and challenges	How is the order picking process at Leman? Which issues does Leman have with the order picking process? What are the improvement areas for the order picking process?	Interviews with the operations manager and IT manager

Warehouse	Activities	What are the main activities at Leman? How are they performed and by who? What challenges does Leman have with their activities?	Company visit at Leman in Vestby, observations through warehouse tours, interviews and meetings with logistics coordinators and operators.
	Configurations	How is Leman organized in terms of layout, customers, employees, storage areas, equipment etc?	Interviews with operators and logistics coordinators, layouts and information received from the warehouse manager, observations in the warehouse, previous work on the same case company
	Storage policies	How are the goods stored and what policies does Leman use for determining the locations?	Observations in the warehouse, interviews with the operations manager and the IT manager, previous work on the same case company

Appendix C

Interview Guide

Interview questions used for interview with Rune Johansen (IT manager) at a visit at Leman 08.04.22. The interview were conducted in Norwegian.

C.1 Layout and Equipment

- Are there currently and pros/cons with your warehouse layout and equipment?
- How is the warehouse organized?
  - Number of shelves, racks, and bays
  - Measurement of these such as heights, widths and lengths
- How many pallets can be stored in the different shelves? Are all pallets the same size/are they standardized?
- What types of trucks do you use?
  - How many do you have?
  - What are the differences between the trucks?
  - How many pallets can each truck carry?
  - How fast do the trucks travel?
- How many pallets can be stored in the outbound-area?

C.2 Products and Storage Locations

- What do you think about using an ABC classification storage policy?
- How often are the classifications of the products updated?
- What triggers the re-classification?
- How are the classifications decided - which data are the input and what types of analyses are done? With what tools?

- Does any products have permanent locations?
- Does any products have fixed classifications?
- How are the storage locations planned?
- What kind of system do you have for the outbound orders? How are the storage locations determined in the outbound area?
- Do you consider weight as a factor for deciding the storage locations?
- When new products arrive, which classification do you give them and based on what information?

C.3 Order Picking

- How much time do you spend on order picking?
- How much time do you spend on the different parts of the order picking process (traveling, full pallet picking, carton picking, packaging, etc.)?
- How often are pallets picked from the C-zones?
- How much of the order picking process is full pallet picking and how much is carton picking?
- How much idle time do you have during a normal day, on average? Is it varying?
- What challenges do you experience with the order picking process in general?
- What do you think are the advantages of how you currently perform the order picking?

C.4 Demand

- Can you tell us about the demand you experience during a normal year? How is it varying and when?
- When is it most busy during a week?
- What happens to new products when they are released?
- How is the demand changing before Christmas and Easter?

C.5 WMS

- Can you tell us about your WMS system?
- How is the WMS dealing with picker routing? Is there a system for which products should be picked first?
- What works well and what are the challenges with your current WMS?

C.6 General

- What do you think are the biggest challenges in your sector in the near future?
- How has the Covid-19 pandemic affected Leman?
- What have been the effects of the new warehouse hall this spring?
- What do you think about implementing reshuffling at Leman?
  - Which benefits do you think reshuffling can provide?
  - What do you think are the main challenges of reshuffling?

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