Ina Snartland

Decision Support for Storage Location Assignment in Warehousing

Master's thesis in Global Manufacturing Management
Supervisor: Anita Romsdal
July 2023

Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Mechanical and Industrial Engineering

NTNU
Norwegian University of
Science and Technology

Ina Snartland

Decision Support for Storage Location Assignment in Warehousing

Master's thesis in Global Manufacturing Management
Supervisor: Anita Romsdal
July 2023

Norwegian University of Science and Technology
Faculty of Engineering
Department of Mechanical and Industrial Engineering

NTNU
Norwegian University of
Science and Technology

Preface

This Master's thesis was conducted in the spring of 2023, concluding my Master's degree in Global Manufacturing Management with a specialization in Production Management at the Department of Mechanical and Industrial Engineering at the Norwegian University of Science and Technology.

I would like to thank my supervisor, Anita Romsdal, for her valuable feedback and guidance throughout the study. Her input and encouragement are greatly appreciated. I would also like to thank Solwr and the case company for their cooperation this semester, devoting time to the study and providing information necessary to conduct the case study, and valuable insight of how a warehouse operates and how the WMS functions.

Ina Snartland
Trondheim, June 2023

Abstract

A warehouse can receive, pick, and ship hundreds of pallets every day. The location of each stock-keeping-unit (SKU) in storage affects the efficiency and cost from transporting the goods. Tasks such as receiving, put-away, order-picking, and shipping goods are labor intensive in manual warehouses, and can be greatly improved by optimizing the SKUs' storage location assignment. As traveling makes up over half of the order-picking time, optimizing the SKUs' storage location can greatly improve order-picking efficiency. In the fast-moving consumer goods (FMCG) industry, goods are subject to large variations in demand, and have the added complexity of perishability. This argues that warehouses operating in this industry should approach the storage location assignment dynamically, ensuring that the SKUs' storage locations are adapted to the fluctuating demand. This entails that high frequency SKUs are located in more favorable locations, such as close to the I/O area. Workers at warehouses are faced with decisions to make at all stages of a good's supply chain. To organize all these activities, the warehouse management system (WMS) is used for decision support. For warehouses that do not utilize mathematical modelling for storage location assignment, this decision support is crucial. Information needs to be presented to the decision-makers in a way that enables them to easily detect when there is a need for change in the storage locations. This information must also be easily accessible from the functionalities of the WMS.

The aim of the study is to investigate which information decision-makers in a warehouse need in order to make high quality decisions regarding the storage location assignment. This is addressed through three research questions, approached through a literature study and a case study. The first question aims to identify how decisions regarding storage location assignment are made today. The second explores which information is needed to support these decisions. The third question addresses how the information can be presented to aid the decision-makers.

The key finding from the study is that the literature offers complex mathematical models for assigning SKUs to storage locations, while the case study shows that there is a team of decision-makers who considers available information for assigning SKUs to optimal storage locations in the forward area. The case study also argues that warehouses in the FMCG industry are heavily constrained by product groups. Which product groups the SKUs at the warehouse belongs to must be considered in every operational decision of the storage location assignment. This information should therefore be presented in the functionalities of the WMS to increase visibility and accessibility of the information.

The main limitation of the study is that only one single case has been investigated. The results are therefore difficult to generalize, and may only be applicable for this particular case. There is, however, reason to believe that the identified decision areas and information needed for decision support is relevant for other retail distribution centers operating in the FMCG industry. Before the results can be implemented, one needs to investigate which data is necessary to attain the information from the WMS. Furthermore, how the information can be presented through the data needs to be explored.

Sammendrag

Et lager kan motta, plukke og sende hundrevis av paller hver dag. Plasseringen av hver vareenhet på lageret påvirker effektiviteten og kostnadene ved transporten av varene. Oppgaver som mottak, innsetting, plukking og forsendelse av varer er arbeidskrevende i manuelle lagre og kan bli betydelig forbedret ved å optimalisere vareenhetenes lokasjon på lager. Da transport utgjør over halvparten av tiden brukt på plukking av ordre, kan optimalisering av vareenheters lokasjon betydelig forbedre effektiviteten ved plukking av ordre. Innenfor dagligvarebransen er varer utsatt for store variasjoner i etterspørsel, og den korte holdbarheten bringer en ekstra kompleksitet. Dette argumenterer for at lagre som opererer i denne bransjen bør tilnærme seg tildelingen av lokasjoner dynamisk for å sikre at vareenheters lokasjon tilpasses den varierende etterspørselen. Dette innebærer at vareenheter med høy frekvens skal plasseres på mer gunstige steder, som for eksempel nær mottak-/utleveringsområdet.

Arbeidere på lagre står overfor beslutninger på alle trinn i en vares forsyningskjede. For å organisere alle disse aktivitetene, brukes et lagerstyringssystem (WMS) for beslutningsstøtte. For lagre som ikke benytter matematisk modellering for tildeling av lokasjoner, er denne beslutningsstøtten avgjørende. Informasjon må presenteres for beslutningstakerne på en måte som gjør det enkelt for dem å oppdage når det er behov for endring i lokasjoner. Denne informasjonen må også være lett tilgjengelig gjennom WMS-funksjonalitetene.

Målet med studien er å undersøke hvilken informasjon beslutningstakere på et lager trenger for å kunne ta kvalitetsbeslutninger angående tildelingen av lokasjoner. Dette blir adressert gjennom tre forskningsspørsmål, tilnærmet gjennom en litteraturstudie og en case-studie. Det første spørsmålet går ut på å identifisere hvordan beslutninger angående tildeling av lokasjoner blir tatt i dag. Det andre utforsker hvilken informasjon som er nødvendig for å støtte disse beslutningene. Det tredje spørsmålet tar for seg hvordan informasjonen kan presenteres for å hjelpe beslutningstakerne.

Hovedfunnet fra studien er at litteraturen baserer seg på komplekse matematiske modeller for å tildele vareenheter til lokasjoner, mens case-studien viser at det er et team av beslutningstakere som vurderer tilgjengelig informasjon for å tildele vareenheter til optimale lokasjoner i plukk-området. Case-studien argumenterer også for at lagre i dagligvarebransjen er sterkt begrenset av produktgrupper. Hvilke produktgrupper vareenhetene på lageret tilhører må vurderes i hver operasjonell beslutning om tildeling av lokasjon. Denne informasjonen bør derfor presenteres i WMS-funksjonalitetene for å øke synligheten og tilgjengeligheten av informasjonen.

Den viktigste begrensningen ved studien er at bare ett enkelt tilfelle har blitt undersøkt. Resultatene er derfor vanskelige å generalisere og kan være relevante for kun dette spesifikke tilfellet. Det er imidlertid grunn til å tro at de identifiserte beslutningsområdene og informasjonsbehovet for beslutningsstøtte er relevant for andre varedistribusjonssentre som opererer i dagligvarebransjen. Før resultatene kan implementeres, må man undersøke hvilke data som er nødvendig for å presentere informasjonen fra WMS. Videre må måten informasjonen kan presenteres gjennom dataene utforskes.

Contents

List of Figures

List of Tables

Acronyms

3PL third-party logistics. 9–11

COI cube-per-order index. 27, 30, 34

COL closest open location. 25, 30

ERP enterprise resource planning. 30, 37–40

FEFO first-expired, first-out. 10, 25, 47

FIFO first-in, first-out. 10, 25, 30

FMCG fast-moving consumer goods. ii, 1, 4–6, 22, 41, 43, 45, 46, 60, 61, 67, 69, 72–75, 77

I/O inbound/outbound. 24, 26–28, 31, 54, 55, 66, 72, 73

KPI key performance indicator. 2, 4, 6, 22, 52, 83

LIFO last-in, first-out. 25, 30

RFID radio frequency identification. 30

SCM supply chain management. 37, 38

SKU stock-keeping-unit. ii, 1, 12–17, 24–35, 46–69, 71–75, 77

SLAP storage location assignment problem. 7, 29, 30, 35, 60, 71, 77

SSCC serial shipping container code. 57–59

WIP work-in-process. 1, 8

WMS warehouse management system. i, ii, vii, 1–3, 5–9, 16, 17, 19, 23, 25, 30, 32, 37–40, 45, 46, 48–51, 55, 56, 59, 60, 63, 67–69, 71–75, 77, 85

1 Introduction

This chapter introduces the background and motivation for the study. The problem statement is described before the research objectives, research questions, and scope of the research are defined. Lastly, an overview of the thesis structure is presented.

1.1 Background

A warehouse is the point in the supply chain where raw materials, work-in-process (WIP), or finished goods are stored. The main tasks in a typical warehouse include the receiving, putaway, order-picking, checking and packing, and shipping of goods. A warehouse can receive, pick, and ship hundreds of pallets every day. The location of each stock-keeping-unit (SKU) in storage effects the efficiency and cost from transporting the goods. Tasks such as receiving, putaway, order-picking, and shipping goods are labor-intensive, and can be greatly impacted by optimizing the SKUs' storage location assignment. Workers at warehouses are faced with decisions to make at all stages of a good's supply chain. To organize all these activities, the warehouse management system (WMS) is used for decision support. Warehouses that operate in the fast-moving consumer goods (FMCG) industry are subject to the added complexity of the products' perishability, as well as their quick turnover and variable demand (Bala & Kumar, 2011).

There are three fundamental decisions that shape the storage function, according to Gu et al. (2007). The first is how much inventory should be kept in the warehouse, the second how frequently and what time should the inventory for a SKU be replenished, and lastly where should the SKU be stored in the warehouse and distributed and moved among the storage areas. The last of the three decisions is referred to as storage location assignment. The storage location assignment concerns challenges in warehouse managerial decision-making regarding optimizing the material handling costs or storage space utilization (Reyes et al., 2019). The importance of problems regarding storage location assignment run deeper than simply affecting operation cost, as it also greatly affects the warehouse performance (Ajol et al., 2018). The storage location assignment concerns the allocation of products into a storage space and optimization of the material handling costs or storage space utilization (Reyes et al., 2019). For this, one needs to consider parameters such as storage area design, storage space availability, warehouse storage capacity, physical characteristics of the products, arrival times, and demand behavior.

A WMS is a complex software package that helps manage inventory, storage locations, and workforce (Bartholdi & Hackman, 2019). The system includes a set of elementary functionalities, typically involving managing quantities and storage locations, controlling and scheduling the means of transport, comprehensive methods and instruments to supervise the system's status, selection of operating and optimization strategies (Nettsträter et al., 2015). It is also to be noted that there is an increasing demand from customers for the vendors of WMSs to enlarge their scope of functionalities.

Janssen et al. (2017) define several factors influencing decision-making when handling big data. Among these are: the knowledge of data and the ability to interpret data and understand how it can be used, the experience of the decision-maker, and process integration, routinizing, and standardization of big data and the big data chain. One of the identified challenges of big data analytics is to find the appropriate tools for analyzing, which techniques to use, and deciding how the data can be visualized (Janssen et al., 2017).

In order to attain an insight in how decisions should be made, one needs to know what is important to the company and what is not (Krauth et al., 2005). Key performance indicators (KPIs) are vital navigation instruments used by managers to understand to what degree their business is successful (Marr, 2012). Technological advancements bring new opportunities for collection, processing, and presentation of data for decision-makers. In order to understand how this can be utilized in warehousing, there is a need to explore how the accessibility of data can be used to an advantage. To realize this, one needs to investigate the decision-makers need and opportunities to make better decisions.

This leads to the question of which information does one need to make different decisions regarding the storage location assignment, and how can it be visualized for improved decision-making.

1.2 Problem statement

Precise control of products leads to improved customer service and less inventory in the system (Bartholdi & Hackman, 2019). This is said to be achieved through systems like WMS. One can argue that decision-making is highly important to maintain and improve this control, especially in labor intensive warehouses. This proves the need for extended efforts in this area. We need research on how one can utilize the technology and systems that are in place to improve decision-making. The study investigates the storage location assignment from the decision-maker's perspective, and how the WMS can be utilized for decision support.

1.3 Objectives and research questions

The overall goal of the study is to investigate which information decision-makers in a warehouse need in order to make high quality decisions regarding the storage location assignment. To support this goal, the research objective focuses on developing requirement specifications for functionalities of a WMS that can utilize this information for decision support. To reach the research objective, the following research questions are investigated.

RQ1: *How are decisions regarding storage location assignment made today?*

The purpose of this research question is to identify the state of decision-making regarding storage location assignment in warehousing today. In order to do so, the question is studied from three different perspectives: the practical perspective, the literature perspective, and the system perspective. The practical perspective is explored through a case study of a warehouse. This perspective describes how decision-makers at a warehouse approach the storage location assignment. The literature perspective is explored through a literature study. The study reviews scientific literature on the storage location assignment, analyzing the proposed approaches to solving storage location assignments. The system perspective is explored through the case of Solwr as a representative for WMSs, as well as through literature on WMSs in general. The goal of this research question is to identify how decision-making regarding storage location assignment is approached from each perspective. Furthermore, the aim of the question is to identify the similarities and differences of the perspectives, with the intention of unifying each approach.

RQ2: *Which information is needed for decision support regarding storage location assignment?*

The purpose of this research question is to identify which information is necessary for decision-makers to make high quality decisions regarding the storage location assignment. The information for decision-makers start out with data on the warehousing processes, and needs to be analyzed before it can be presented to the decision-makers. The research question is therefore approached with a user perspective, aiming to identify the information that is useful for the people making decisions. This is studied through interviews with decision-makers at a warehouse and through the literature study.

RQ3: *How can information be presented for decision-makers to best aid them in decision-making regarding storage location assignment?*

The purpose of this research question is to explore the possible opportunities that data presentation can bring to decision-makers. To answer the question, the findings from **RQ1** and **RQ2** are used to further explored the functionalities of WMSs. The research question aims to identify new functionalities of WMSs for decision-support, or areas for improvement in existing functionalities. This is explored through the case of Solwr, the case company utilizing Solwr's WMS, and the literature study. The question is approached from the decision-makers perspective, evaluating how information can be presented to aid them in deciding whether to move a product or not.

1.4 Scope

Inside the scope of the study is decision-making within planning and control of warehouse operations. The study considers all three levels of decisions, strategic, tactical, and operational, but mainly focuses on the operational decision level, as the focus of the study is on the decisions that are made on a daily basis. Within this, the scope includes incoming and outgoing goods, investigating how they are assigned to storage locations at the warehouse. Secondly, there is a focus on the functionalities a WMS should provide for decision-makers, and how it can be presented for decision-support. The initial focus of this is on identifying the information decision-makers need, laying the grounds for integration into dashboards, visualization, KPIs, etc.

As the scope focuses on what information decision-makers need from a user perspective, technical solutions are out of scope. For realization of results, there are further steps needed, such as identifying which data is necessary to provide the information for decision support. These should be done by someone with competence in data engineering or programming.

1.5 Thesis structure

The structure of the report is illustrated in fig. 1.1. The three research stages connecting the research questions to the chapters where they are discussed, represent the data gathering process throughout the study.

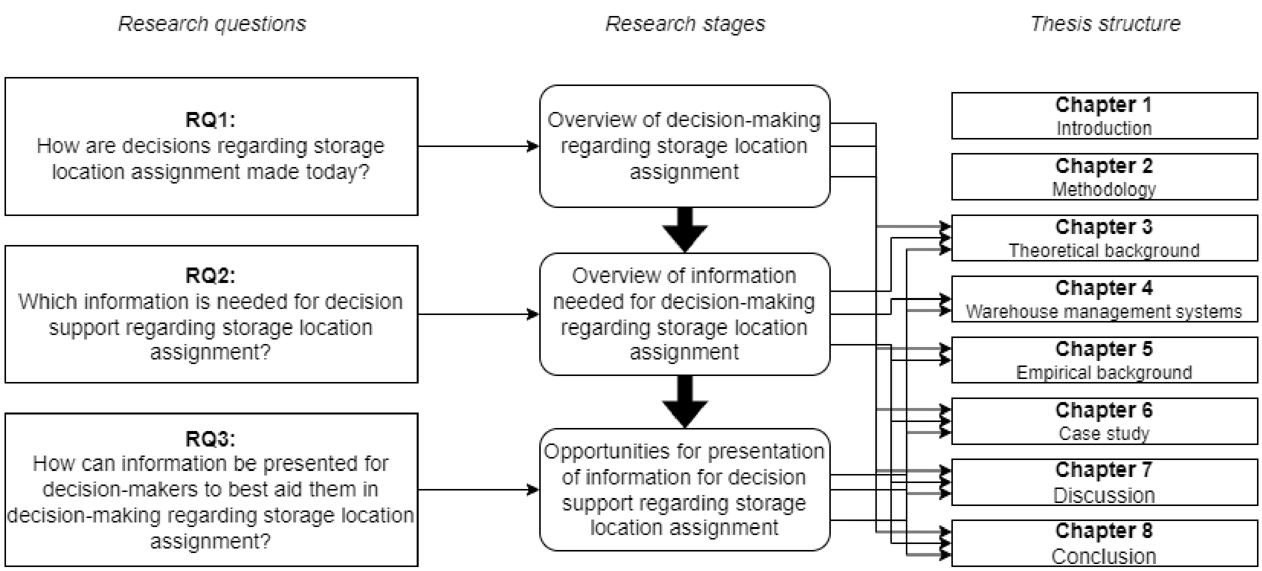


Figure 1.1: Structure of the report in relation to the research questions

The first research stage involves obtaining an overview of decision making regarding storage location assignment. This is achieved through the theoretical background, the empirical background, and the case study. The theoretical background poses as the literature perspective of decision-making in storage location assignment, while the empirical background provides context of the FMCG industry. The case study explores the practical perspective of the decision-making. Furthermore, the findings are discussed in chapter 7 and concluded in chapter 8.

The second research stage explores the information needed for decision-making regarding storage location assignment. This is investigated in the theoretical background, warehouse management systems, empirical background, and the case study. The theoretical background provides information about the literature perspective for the research question. The warehouse management systems chapter provides information about what information is available from the WMS. The empirical background identifies necessary information for storage location assignment of FMCG. The case study offers a practical perspective of what information decision-makers need for storage location assignment. The results are discussed in chapter 7 and concluded in chapter 8.

The third and last research stage focuses on the opportunities for presentation of data for decision support regarding storage location assignment. This is explored through the theoretical background, warehouse management systems, and the case study. The theoretical background identifies how individuals make decisions, and how presentation of data can improve decision-making. The warehouse management systems chapter presents general functionalities of WMSs. The case study offers more detailed information about the WMS's functionalities and how the information is presented to the user, as well as insight of what the decision-maker needs to make decisions. The results are discussed in chapter 7 and concluded in chapter 8.

2 Methodology

The methodology is comprised of two methods. The first method is the literature study, representing the literature perspective of the research questions. The second method is a case study, which investigates a company called Solwr and one of the companies which utilizes their WMS at their warehouse. Solwr is in this study a representative of WMSs, providing information about their functionalities which can be used when dealing with the storage location assignment. The case company provides first hand experience with decision-making within warehousing and the use of the WMS in practice. This chapter presents and describes the research process through these methods.

2.1 Literature study

The first method for the project is a literature study. Through the literature study, basic terms and methods are defined. The main search engines used in the project are Scopus, Google Scholar, and Oria, which provide scholarly articles, literature reviews, scientific articles, and textbooks. The findings form the basis of the theoretical aspects in the study, providing a fundamental understanding of the topic before reviewing research on the same topics. This is the basis for the literature perspective, which is one of the three perspectives discussed when answering the research questions.

The first round of searches included search words grouped into the key theoretical aspects of the study: warehousing, warehouse operations, storage location assignment, WMS, decision-making, and KPIs. After the initial selected articles, studies, and books were reviewed, backwards searches were made, looking through the reference lists for other relevant sources. After I had obtained an understanding of the key topics that were to be included in the study, more targeted searches were conducted, searching for specific topics that the original articles provided insufficient information. The theoretical aspects were further explored with the intention of identifying how the literature approaches the storage location assignment.

2.2 Case study

The first object of the case study is Solwr, which is a provider of the WMS called Trace. The information used for the study includes a feature descriptions and a structured query language document of all the functionalities of the WMS. These have been used to understand which functionalities and data are available from the system. The findings from the case study of Solwr form the basis for the system perspective, which is the second perspective that is discussed when answering the research questions.

The second object of the case study is a warehouse which operates in the FMCG industry. Through a company visit on May 19th 2023 at their warehouse, an understanding of how their storage works was obtained. In addition to the company visit, two interviews were conducted. The first interview took place May 11th 2023. The aim of this interview was to get a broad understanding of how the case company plan their storage location assignment. The interview also had the intention of mapping the focus areas of the master thesis, in order to plan the next interview with a person from the company with relevant knowledge. The next interview took place on May 19th 2023. The interview was with the manager of the company. This was a semi-structured interview, using the interview guide from appendix A. The interview was in Norwegian. To validate the results from the case study, the finished thesis was sent to the company for approval.

The two perspectives of the case study are compared to the perspective from the literature study. The three perspectives are explored and compared to answer the research questions, investigating the gap between theory of the storage location assignment problem (SLAP), which refers to solving a mathematical problem of the storage location assignment through complex models, and problem solving decision-makers in warehouses face daily, and how the WMS can be utilized for decision support. The results of the analysis of the literature study and the case study are identified challenges and opportunities. These are based on abductive reasoning, which is the forming of conclusions based on the available observations. While the literature study has been conducted to identify opportunities, the case study has been conducted to obtain a deeper understanding of how decision-making related to storage location assignment is conducted in practice, and what the WMS can offer as decision support.

3 Theoretical Background

This chapter provides the necessary theoretical background for the study. Firstly, warehousing, warehouse operations, and a brief introduction to warehouse management system (WMS)s are presented. Secondly, storage location assignment is investigated, followed by decision-making. Lastly, challenges and opportunities of the theoretical background is summarized.

3.1 Warehousing

Van Den Berg (1999) defines warehousing as all movement within warehouses and distribution centers, namely receiving, storage, order-picking, accumulation and sorting and shipping. Kay (2015) defines the warehouse as the point in the supply chain where raw materials, work-in-process (WIP), or the storing of finished goods for varying lengths of time. In addition to these activities, Heragu* et al. (2005) add the protection of goods while in storage. Furthermore, Kay (2015) state that warehouses can be used to add value to the supply chain through storage or transport economies. The use of storage allows for product to be available when and where it is needed, while transport economies enables the product to be collected, sorted, and distributed efficiently. One of the benefits of keeping storage is that it allows for production to operate more efficiently. In addition to this, there are usually economic benefits associated with the storage of raw material, WIP, and finished goods (Kay, 2015).

According to Heragu* et al. (2005), a warehouse is generally divided into three areas to perform the necessary functions of a warehouse: reserve storage area, forward area, and cross-docking area. The reserve area is where goods are stored until required for shipping or for performing value added services or order collation. The forward area is where the order collation is typically performed. This area may also be used to store fast-moving goods that do not occupy much space. Cross-docking refers to the process of moving items directly from the receiving trucks to the shipping trucks (Heragu* et al., 2005).

3.1.1 Warehouse operations

The overall tasks of a warehouse are to reorganize and repackage products (Bartholdi & Hackman, 2019). Typical warehousing functions include the receiving, put-away, storing, order-picking, checking and packing, sorting, unitizing, and shipping of products (Bartholdi & Hackman, 2019; Kay, 2015). Bartholdi and Hackman (2019) categorize the physical processes of reorganization of product into inbound and outbound processes. The inbound processes include receiving and put-away of product, while outbound processes are order-picking, checking, packing, and shipping. Related to these processes, order-picking and travel are the most labor-intensive (Bartholdi & Hackman, 2019). As labor is what carries the most expense in a warehouse, the reduction of labor needed for these processes is the most advantageous to investigate.

Kay (2015) defines receiving as the process of unloading, verifying, inspecting, and staging of material transported to a warehouse. In some cases, the process also includes sorting and repackaging of material. Purchase orders are sent to supplier in order to request to ship material to a warehouse. The supplier sends an advance shipment notice to the WMS (Kay, 2015).

According to Kay (2015), the put-away process includes the movement of material from the receiving area to storage. To prepare for this process, an algorithm in the WMS is used to search for and validate locations where each movable unit in the put-away queue can be stored. The efficiency of warehouse operations is dependent on the performance of the put-away algorithm. Inventory and location attributes used in the algorithm are related to the required environment, container type, product processing type, velocity, and preferred put-away zone (Kay, 2015).

A strategy to improve the efficiency of the order-picking process at the warehouse is to have a separate forward picking storage area (Kay, 2015). Storage location for similar items are typically consolidated into a single location to improve space utilization. To improve handling efficiency, items are moved to different storage locations. To verify the accuracy of inventory records, cycle counting is performed, which is the counting of contents of storage locations. The majority of the storage space is typically occupied by storage for pallet and case picking (Kay, 2015).

3.1.2 Types of warehouses

Bartholdi and Hackman (2019) introduce five types of warehouses:

- Retail distribution center
- Service parts distribution center
- Catalog fulfillment (or e-commerce)
- 3PL warehouse
- Perishables warehouse

A retail distribution center provides a link from suppliers to retail stores (Dasgupta et al., 2015). The immediate customer of the distribution center is a retail store (Bartholdi & Hackman, 2019). The retail distribution centers are typically part of a larger retail distribution network, comprised of several central, regional, and local distribution centers (Holzapfel, Kuhn, & Sternbeck, 2018). The distribution centers are often subject to a large volume of products that are to be shipped to the retail stores. At the distribution centers, one of the main tasks is to break bulk and distribute product to the retailers (Dasgupta et al., 2015). The inventory management at the centers is complicated and challenging due to product variety and lead times. Products are stored temporarily at the distribution centers, until they are picked according to store orders for shipping (Holzapfel et al., 2018).

Service parts distribution centers are part of the service part supply chain, consisting of forward stocking locations, distribution centers, and a center hub (Ouyang et al., 2019). The distribution centers typically hold spare parts for expensive capital equipment (Bartholdi & Hackman, 2019). Retailers in need of service parts depend on the distribution centers to carry full sets of parts as needed (Thomopoulos & Thomopoulos, 2016). In the service part supply chain, suppliers typically ship stock to one or more distribution centers, who further distribute service parts to a series of retailers.

Catalog fulfillment or e-commerce distribution centers typically receive small orders from individuals by phone, fax, or the internet (Bartholdi & Hackman, 2019). The distribution center is typically equipped with smart warehouse systems for warehousing activities (Tan, Li, & He, 2021). Order-picking is utilizes automatic picking systems, sorting is automated, and automated guided vehicles are used for handling parcels. Orders are typically small, but many, and are to be filled and shipped immediately after receipt (Bartholdi & Hackman, 2019).

A 3PL warehouse is a warehouse where a company outsource its warehousing operations (Bartholdi & Hackman, 2019). 3PL warehouses operate in a dynamic environment (Baruffaldi, Accorsi, Manzini, & Ferrari, 2020). Managers of 3PL warehouses often address a wide number of clients, all with specific requirements in terms of standards, service level, infrastructure, tasks, etc. The 3PL providers gain economies of scale to a higher degree than the customers would by themselves (Bartholdi & Hackman, 2019).

Perishables warehouses may handle food, fresh flowers, vaccines, or other products requiring refrigeration to protect the products' short shelf lives (Bartholdi & Hackman, 2019). The inventory management of these warehouses are faced with challenges regarding temperature, requirements for product rotations according to FIFO or FEFO, and restrictions on how product is handled. All stages of the supply chain of perishable products have high demands for quality, timeliness, and safety (Göransson, Nilsson, & Jevinger, 2018).

There is a systematic way of thinking about a warehouse system regardless of industry (Bartholdi & Hackman, 2019). Selection of equipment and organization of material flow is largely determined by inventory characteristics, throughput and service requirements, footprint of the building and capital cost of equipment, and the cost of labor.

3.1.3 Material flow

Bartholdi and Hackman (2019) state that the material flow form the foundations for warehouse analysis. The supply chain is the sequence of processes through which product moves from its origin towards the customer. The material flow of these products can be described through the fluid model. In the fluid analogy, the warehouse represents storage tanks along a pipeline. While in-compressible fluid will flow faster in narrower segments than in wider segments of a pipe, products in the supply chain will move faster where there is little inventory, and slower with large amounts of inventory. The concept of just-in-time can be roughly compared to the reduction of parameters of the pipe. That is, increasing the speed of the product flow, and reducing the flow time and in-transit inventory (Bartholdi & Hackman, 2019).

Bartholdi and Hackman (2019) further discuss guidelines to warehouse design and operation, with the material flow in focus. The first guideline is to keep the product moving. Avoiding starts and stops avoids extra handling and additional space requirements. The second guideline is to avoid layouts that impede smooth flow. Lastly, the need to identify and resolve bottlenecks to flow is highlighted (Bartholdi & Hackman, 2019)

3.1.4 Layout

Bartholdi and Hackman (2019) describe the layouts of three different types of warehouses: a *unit-load* area, a *carton-pick-from-pallet* area, and a *piece-pick-from-carton* area. A unit-load warehouse is the simplest type of warehouse, where only a single common unit of material is handled at a time (Bartholdi & Hackman, 2019). The picking of a unit-load refers to the picking of full pallets (Kay, 2015). An example of a unit-load warehouse is a 3PL warehouse, which receives, stores, and forwards pallets (Bartholdi & Hackman, 2019).

Expenses related to the warehouse space is typically tallied by the square-foot or square-meter (Bartholdi & Hackman, 2019). To reduce the cost related to space, one wants to have many pallet-positions per unit area. To achieve this, one needs to take advantage of vertical space and/or use deep lanes (Bartholdi & Hackman, 2019).

Taking advantage of vertical space can be done through racking or stacking (Bartholdi & Hackman, 2019). The benefits and disadvantages of the two are summarized in table 3.1

Table 3.1: Rack vs. stack
(based on Bartholdi and Hackman (2019))

	Benefits	**Disadvantages**
Rack	Allows for pallets to be stored independently of each other May reduce labor through easy storage and retrieval May create additional pallet positions May protect product from damage May help provide a safer work environment by avoiding unstable pallet stacks	The additional cost of the rack itself
Stack	Allows for many pallet positions per unit of floor space No additional cost of a rack	Heavy or fragile pallets or pallet with uneven surfaces cannot be stacked very high, leading to unusable space above

When considering whether to move a SKU to a pallet rack instead of floor storage, one needs to take into account the cost of the rack (Bartholdi & Hackman, 2019).

Lane depth

The use of aisles provide accessibility, but not storage (Bartholdi & Hackman, 2019). This means that they are not directly revenue-generating. Therefore, one wants to reduce aisle space to the minimum necessary, while still providing adequate accessibility. By storing product in lanes, additional pallet positions can share the same aisle space, reducing the cost. A double-deep layout opens up for fitting more pallet positions in the same floor area than a single-deep layout. The double-deep layout also results in not all pallets being directly accessible for the picker. The directly accessible pallets are also not available for reuse until the interior pallet location in the same lane becomes available. This means that deeper lanes produce more pallet storage, but are of diminishing value. A pallet position is the floor space required to hold a pallet. This includes the required gap between one pallet and the adjacent one (Bartholdi & Hackman, 2019).

In most warehouses, a lane is dedicated entirely to a single SKU, to avoid double-handling pallets (Bartholdi & Hackman, 2019). This saves time, but incurs a cost in space. If one pallet is retrieved from the lane, the space is unoccupied, but unavailable to other SKUs. The deeper the lane, the greater the cost (Bartholdi & Hackman, 2019). This is referred to as the honeycomb loss. Kay (2015) defines the honeycomb loss as the excess storage that cannot be utilized. This is the price paid for accessibility, which occurs when the storage space is dedicated to that of only a single SKU, not storing items from different SKUs in that same storage location to avoid blocking access (Kay, 2015). To maximize space efficiency, one can store SKUs in a lane depth that minimizes floor space-time that is unoccupied, but unavailable to other SKUs (Bartholdi & Hackman, 2019). The total space lost from storage during the inventory cycle is the sum of the honeycomb loss and the accessibility costs.

Labor related to the warehouse layout

The movement of forklifts or other unit-load equipment only adds value if the equipment is moving with a unit (Bartholdi & Hackman, 2019). Because of this, one wants to minimize the time that equipment travels without carrying a unit. Bartholdi and Hackman (2019) refers to this as *dead-heading*, when a forklift is traveling with an empty fork. In the warehouse, movement is typically to stow or to retrieve pallets. One of the simplest and most common protocols is for the forklift to be devoted to unloading a trailer and stowing the pallets one by one, and retrieving pallets and loading them into a trailer. This is referred to as *single-cycle*. Single-cycles result in dead-heads for at least half of the traveling time of the forklift, as they return empty to receiving to unload or to retrieve another pallet for shipping.

Bartholdi and Hackman (2019) suggest two ways one can reduce the labor time. The first is by storing product in convenient locations, reducing the travel time with the pallet. The second option is to reduce dead-heading by careful interleaving of put-aways and retrievals. This is referred to as *dual-cycle*, and is when a forklift travels directly to pick up another pallet. A dual-cycle is not advantageous when product is shipped and received at different times of the day, such as shipped in the morning and received in the afternoon, and is dependent on the layout of the warehouse allowing such movement. Deciding where to locate the receiving and the shipping area also affects the trucks' travel time (Bartholdi & Hackman, 2019). The storing of product in convenient locations is revisited in section 3.3, discussing the storage location assignment.

Layout of a carton-pick-from-pallet area

A *carton* or a *case* generally refers to a rectangular box that weighs between 2.3-22.7 kg, can be handled by one person, is conveyable, and can be stored on a pallet (Bartholdi & Hackman, 2019). The restocking of this area is that of a unit-load process, while the order-picking differs. This is explained through the forward area.

Forward area

The forward area is an area used to enable more efficient order-picking (Kay, 2015). This area is limited for space, resulting in the need to be restocked from a different place in the warehouse (Bartholdi & Hackman, 2019). The most common forward pick area, as stated by Bartholdi and Hackman, is the ground floor of a pallet rack. Popular SKUs may be picked from the ground level, and replenished by dropping overstock pallets from above.

For the picking of cartons, Bartholdi and Hackman (2019) state that there are two typical flows of cartons through the warehouse. The first is to pick the cartons from the bottom, which is the most convenient level. When this level is emptied, it is restocked by dropping a pallet from above. Newly arriving pallets are inserted into the overstock. In this case, the forward area is the ground floor pallet locations, and the reserve includes all higher locations. The second way is to use a conveyor. With very high volume distribution of conveyable product, cartons may be picked from a pallet flow rack to the conveyor. The order-picker will walk up and down the aisle picking cartons, labelling them with destination, and placing them on the conveyor, which takes them to shipping. The forward pick area in this case includes all pallet locations in the pallet flow rack, and reserves may be in a separate area of the warehouse, or very high pallet racks. The organization of a conveyor and a forward are is similar in a way that a small number of cartons from which it is convenient to pick from are restocked from a bulk area (Bartholdi & Hackman, 2019).

3.1.5 Order-picking

Kay (2015) defines order-picking as the removing of material from storage in response to specific customer orders or shop orders. Order-picking is the most resource-intensive process performed in a warehouse (Scholz & Wäscher, 2017; Bartholdi & Hackman, 2019; Kay, 2015; Frazelle, 2016; Lanza, Passacantando, & Scutellà, 2022; Sgarbossa, Romsdal, Johannson, & Krogen, 2020). The process is at the intersection of warehousing and order processing, as the physical material handling processes associated with retrieving items efficiently is combined with the information processing associated with searching and updating inventory records as orders are filled. Order-picking is considered the most critical activity in most distribution operations, as it is the point where the customer expectations are actually fulfilled (Kay, 2015).

An order indicates the type and the quantity of items the customer wants (Kay, 2015). The type of item is referred to as a SKU, and a *unit* is an instance of a SKU. Each pair of a SKU and a quantity in an order is an *order line*. A *pick list* indicates the sequence at which the storage locations of SKUs are to be visited, along with number of units to be picked from each location. *Waves* are the planning periods which groups of orders are picked during (Kay, 2015).

Methods of order-picking

Kay (2015) introduces four methods of order-picking: discrete picking, zone picking, batch picking, and zone-batch picking. When practicing *discrete* picking, a single picker picks all items for a single order. For *zone* picking, each picker picks items of an order located in an assigned zone. *Batch* picking implies that a single picker picks all of the items for multiple orders. Lastly, the *zone-batch* picking method combines zone- and batch picking, having multiple pickers each pick portions of multiple orders (Kay, 2015). Benefits and disadvantages of each method is presented in table 3.2.

Table 3.2: Benefits and disadvantages for methods of order-picking (based on Kay (2015))

Order-picking method	Benefits	Disadvantages
Discrete	An entire order can be packed while picked No need for sortation and consultation	Travel time can be excessive if there are few picks per order Congestion in aisles can occur when there are many orders being picked
Zone	Allows different techniques and equipment for each zone Can reduce travel time if fast moving SKUs are located in the most accessible locations	Can be difficult to balance amount of work in each zone
Batch	Can reduce travel time when batched orders have items located in close proximity Can reduce search time if multiple orders visit common locations	Items must be sorted into individual orders It may take long to accumulate enough orders with items located in close proximity
Zone-batch	More opportunities for batching, as items in the same zone are in close proximity More orders with larger size items can be batched, as the picker does not carry full orders	Requires the highest degree of coordination May require both consolidation and sortation

Levels of order-picking

In addition to *pallet* picking, also known as *unit-load* picking, where full pallets are retrieved, known from section 3.1.4, there is also *case* picking and *piece* picking (Kay, 2015). Case picking refers to the retrieval of full cartons of items. This level can also be termed *split-case* picking, if inner packs of items from cartons are retrieved. Piece picking is the picking of individual units of issue to the customer of an item, also referred to as *broken-case* picking. Pallets and cases take up the most storage space (Kay, 2015).

Activity profiling

Kay (2015) defines activity profiling as a systematic analysis of items and orders handled in a warehouse, with the objective of improving warehouse design and operation. When designing an order-picking system, there are several factors to be considered. For this process, Kay states that within this process, a representative set of customer orders are used together with the item master file, and parameters used for different warehouse decisions are generated. The decisions in question are related to equipment, methods selection, and slotting, known as the assignment of items to storage locations. The warehouse design parameters are the total number of lines in all orders over a period of time, lines per order, cube per order, flow per item, lines per item, cube movement, and demand correlation (Kay, 2015).

Order-picking process

Kay (2015) summarizes the general order-picking process in three steps:

1. Identifying the location of each pick.
2. Confirming the pick.
3. Indicating any shortage of product.

There are several ways to support picker in this picking process, through communications equipment and identification equipment. Kay (2015) introduce four methods for this: pick-to-paper, bar-code scanning, pick-to-voice, and pick-to-light.

Through *pick-to-paper*, the picker is given a paper pick list, which includes locations, SKU ID, quantity, and units of measure of all items, in the sequence that they should be picked (Kay, 2015). The pick tour is generated from the WMS. To indirectly confirm each item that as it is picked, the pick cart has a weight scale that can be used, with the option to note shortages on the pick list. This method is reasonably fast, low-cost, low-tech, and allows for experienced pickers to see the entire tour and modify tours if they perceive them to be inefficient. The method also bares some disadvantages. Firstly, the fact that the paper list is held by the picker and can be made changes to, can interfere with picking, resulting in slower pick rates. There is also no direct pick confirmation. As the lists are on paper, there is a lack of communication link to the WMS. There is no real-time re-balancing of the pick lines, and shortages are not communicated until the end of the tour. This delays the updating of the WMS (Kay, 2015).

Bar-code scanning, as defined by Kay (2015), consists of three steps. Firstly, the location, quantity, and SKU ID of items to pick are presented to the picker on a portable data terminal. Secondly, the picker scans or keys-in the check digit, confirming location. Thereafter, the picker scans the unit or keys-in confirmation of the pick. At this stage, they also note any shortages. If there are more picks on the list, the process is repeated until there are no more picks left. Each label includes a bar-code and a printed address, including a check digit. The check digit can be typed into the portable data terminal using the keypad, providing a fast means of location identification, when one is unable to scan a location label. The portable data terminal communicates with the WMS via a radio frequency link. An advantage of this method is that it provides real-time pick confirmation and shortage indication, unlike *pick-to-paper*. Another advantage of the method is that bar-code labels and readers are low cost. A disadvantage of the method is that it may slow down the picking process. The portable data terminal may also interfere with picking. Lastly, the method usually does not display the entire pick tour to the picker. The picker does therefore not have the opportunity to modify the tour to improve its efficiency (Kay, 2015).

Kay (2015) describes *pick-to-voice* through three steps. Firstly, the SKU ID and quantity of an item to pick are communicated to the picker through a headset. Secondly, the picker says the check digit to confirm the location. Thereafter, the picker states the quantity picked, followed by the work "picked" to confirm the pick, indirectly noting any shortage. If there are more picks on the pick list, the process is repeated. This method introduces the advantage of a hands-free real-time pick confirmation and shortage indication. The method is also low cost. A disadvantage of the method is that speaking may slow down picking. The method also bares some resemblance to *bar-code scanning*, as the tour is unknown to the picker. This makes it difficult for the picker to modify a pick tour to improve efficiency (Kay, 2015).

The last method presented is *pick-to-light*. This is stated by Bartholdi and Hackman (2019) to be the most common picking method. Kay (2015) describes the method in two steps. Firstly, the quantity of a pick is indicated by LED on a display at the pick location. The picker then hits a button on the display to confirm the location and pick. There is a decrement button for which one can note shortage. In batch picking, displays can also be used to indicate and confirm packing. If there are any more picks left, the process is repeated. The increment button on the display is only used for cycle counting. The displays communicate with the WMS via wire network in the rack. This method has the advantage of very fast picking and packing. It also provides real-time pick confirmation and shortage indication. The main disadvantage of the method is the cost. The display cost is proportional to the number of pick locations, whereas for the other methods, the equipment cost is proportional to the number of pickers (Kay, 2015).

When picking cartons for pallets, the order-picker needs to consider how they build the pallet. Kay (2015) states that the assembly of cartons to pallets is complicated, as cartons of many shapes, sizes, weights, and fragility must be packed tightly and quickly. Large, heavy items should be placed at the bottom of the pallet, for stability and to avoid damage to lighter items, while light, small items should be placed on top. To achieve this efficiently, the storage locations should support the logical picking path, from heavy items to light items (Kay, 2015).

Table 3.3: Percentage of order-picking time for each activity of the order-picking process (Adapted from Bartholdi and Hackman (2019))

Activity	**% Order-picking time**
Traveling	55%
Searching	15%
Extracting	10%
Paperwork and other activities	20%

Brynzér and Johansson (1996) discuss which factors affect the order-picking time. Long picking time depends on the distance that the picker needs to travel to pick all items for an order. As presented in table 3.3, Bartholdi and Hackman (2019) state that traveling makes up over half of the total order-picking time. This is, however, not the only factor (Brynzér & Johansson, 1996). Whether or not the picker perceives the items going into one order to be placed in a logical order can affect the order-picking time. The order-picking process is highly dependent on the storage location of each SKU at the warehouse. An optimized picking-route can only provide the best route given the location of product (Brynzér & Johansson, 1996). This leads to the assignment of storage location.

In high-volume distribution, such as supplying product to retail stores, customer orders are typically large and similar (Bartholdi & Hackman, 2019). In these cases, the order-picker is likely to make many picks per unit of distance traveled, and likely to follow a common path along an aisle of flow rack.

3.2 Decision-making

This section discusses different aspects of decision-making. Firstly, the different type of decisions a company can make, differentiating between strategic, tactical, and operational decisions are introduced. Secondly, how individuals make decisions is discussed, before introducing big data's role in decision-making. Furthermore, key performance indicators are discussed, and the difference between lead and lag indicators is explored. Lastly, the importance of presenting data for decision-makers is visited.

3.2.1 Decision levels

Koliba et al. (2022) separate between strategic, tactical and operational decisions. Strategic decisions are long term, comprehensive, typically made by executive leaders, and are phrased as questions using why and when (Koliba et al., 2022; Srinivas et al., 2021). Bruel (2016) lists five main strategic choices: key competitiveness variables in each segment, choices on guiding principles, outsourcing choices, and resource-allocation decisions. After a strategic framework has been defined, operational management takes over to ensure efficient implementation (Bruel, 2016). Tactical decisions are medium term, involve linked, are typically made by mid level managers, and are phrased as questions using where and how (Koliba et al., 2022). Decision areas for tactical decisions can be related to scheduling shipments for transportation, production quantities over different time periods, etc (Srinivas et al., 2021). Operational decisions are short term, specific, typically made by front line workers, and comes down to how something is to be executed. Srinivas et al. (2021) state that operational decisions are related to activities, such as allocation production or inventory in response to customer orders, placing replenishment orders to maintain inventory, selecting dates for delivery, etc.

3.2.2 Individuals as decision-makers

Raghunathan (1999) investigates the impact information quality and decision-maker quality has on actual decision quality. Raghunathan defines decision quality as the accuracy of decisions, information quality of an input as the probability that the value of input believed by the decision-maker is the actual value, and decision-maker quality as the quality of the decision-making process, measured in accuracy (Raghunathan, 1999).

Lunenburg (2010) discusses how individuals make decisions. This is described through the rational model and the bounded rationality model. The rational model is assumed to be applicable for administrative decision-making. In cases like these, alternatives, outcomes, and decision criteria are known. This allows for the possibility to make the optimum choice, and then implement it. The process of the rational model is given by six steps: identify the problem, generate alternatives, evaluate alternatives, choose an alternative, implement the decision, and lastly evaluate the decision effectiveness (Lunenburg, 2010).

The bounded rationality model, as described by Lunenburg (2010), refers to decisions based on incomplete and inadequate comprehension of the true nature of the problem being faced. In these cases, decision-makers can never be successful in generating all possible alternative solutions for consideration. As it is impossible to predict accurately all consequences associated with each alternative, the alternatives are evaluated incompletely. As a result, one cannot choose the alternative based on a criteria related to maximization or optimization. Instead of determining which alternative is optimal, one needs to consider alternative criteria. Lunenburg list several approaches to decision-making within bounded rationality: satisficing, heuristic, primary/recency effect, bolstering the alternative, intuition, and incrementalizing. Satisficing refers to choosing the first alternative that satisfies minimal standards of acceptability, without further exploring all possibilities. Heuristics is a way of using rules that simplify complex decision-making situations. The primacy effect occurs when the decision-maker is influenced by information early in the search process. On the contrary, the recency effect refers to the decision-maker being influenced by information that arises late in the search process. Both effects refer to a bias from the decision-maker. Another type of bias is the bolstering of the alternative. In this case, the decision-maker will search for information that rationalizes the choice that the decision-maker is predeterminant to make. Intuition is also considered an aspect of bounded rationality. This means that the decision-maker already has a quick apprehension of a decision, based on past experiences. Lastly, incrementalizing is the approach of making small changes to an existing solution, based on successive limited comparisons (Lunenburg, 2010).

3.2.3 Big data for decision-making

WMSs utilize big data. Big data is often related to predictive analysis (Janssen et al., 2017). This refers to the techniques that predict future outcomes to uncover patterns and find relationships in data. In order to be equipped to make decisions using the WMS, one therefore needs an understanding of big data and how it is used.

Janssen et al. (2017) describe the big data process as starting with data capturing and ending in decision-making. An example of this process is given by six steps:

1. Data capturing
2. Data storage
3. Data searching
4. Data sharing

5. Data analysis

6. Data visualization

As Janssen et al. (2017) discuss, one often assume that big data results in better decisions. However, it is unclear which factors actually influence the decision-making quality, and how one can improve decision-making quality (Janssen et al., 2017). Raghunathan (1999) states that the decision quality improves with improvement of information quality. Furthermore, the affect of improved information is only fully exploited by decision-makers with accurate knowledge of the relationships of the problem variables. If the decision-maker does not have sufficiently accurate knowledge of the problem, (Raghunathan, 1999) states that the decision quality may even decrease.

Janssen et al. (2017) identified 11 factors influencing the decision-making quality, presented in table 3.4. This shows how having access to big data does not necessarily improve decision-making quality. One needs to have the right tools to utilize the big data. In short, the factors touch on the collaboration and knowledge exchange between big data providers, analysts, and staff, the standardization and flexibility of the systems in place using big data, as well as the quality of the big data that is presented.

Table 3.4: Factors influencing decision-making quality (based on Janssen et al. (2017))

Factor	Description
Contractual governance	Contracts with big data providers to increase data quality Agreements between organizations to ensure mutual understanding of big data Improve communication
Relational governance	Building trust among organizational entities Sharing knowledge necessary to interpret big data Communication to understand the process data
Big data analytics capabilities	Finding the right tools for analyzing Identify which techniques to use and how big data can be visualized
Knowledge exchange	Transferring data and knowledge of data to be able to interpret data and understand how it can be used Analysts need more knowledge of context off the use of big data analytics to make it easier to find patterns and relationships
Collaboration	Overcoming fragmentation and create a big data chain through collaboration with big data providers, analysts, and decision-makers Lack of collaboration may block creation of valuable application
Process integration and standardization	Enhancing the big data chain Lower efforts and cost to use big data and big data analytics
Routinizing and standardization	Routinizing the big data chain improves big data velocity Helps inspectors make decisions in real-time
Flexible infrastructure	Determines ability and amount of effort necessary to handle and process the data Systems integration improves handling of big data Manual work results in long lead time
Staff	Finding specialists able to deal with big data and knowledge of big data analytics
Data quality of the big data sources	Big data provides little value if not accurate or if people are unable to interpret the decisions
Decision-maker quality	Decision-makers should be able to interpret the outcomes of the analytics and understand implications Experienced decision-makers make better and faster decisions

3.2.4 Key performance indicators (KPIs)

A key performance indicator (KPI) is a measurement which evaluated how a company executes its strategic vision Marr (2012) discuss the use of key performance indicator (KPI)s for managers. Marr define KPIs as vital navigation instruments which are used by managers to understand to what degree their business is successful. Without identifying these vital management metrics, a consequence may be that managers drown in data, attempting to collect and report a vast amount of everything that is easy to measure (Marr, 2012). As a result, one may not identify any data that can be used for measuring the company's performance.

Marr (2012) states that there are six perspectives of KPIs: financial, customer, marketing and sales, operational processes and supply chain, employee, and corporate social responsibility. For development of the KPIs, one needs to start with the company's strategy and identify the objectives the business is aiming to achieve (Marr, 2012). This is to ensure that the KPIs measure what is important for the company. As (Krauth et al., 2005) state, attaining insight of how decisions should be made starts with knowing what is important for the company and what is not.

Krauth et al. (2005) discuss KPIs in light of general management, supply chain management, logistics service provision, and warehousing. They have identified a set of key points that are important from a customer perspective in a dedicated fast-moving consumer goods (FMCG) warehouse. The first point is the importance of fast and reliable delivery. This is important as stock outs often result in lost in lost sales. The second point is the importance for customers regarding the product price. Price is important for companies to reach for a competitive advantage. Lastly, customers value the flexibility. A warehouse must therefore be able to accommodate increases and decreases in the flow of goods (Krauth et al., 2005).

Kusrini et al. (2018) have defined a set of KPIs in warehousing, indicating the importance weight of each warehouse KPI. The activities in question are receiving, put-away, storage, order-picking, and shipping. For receiving, the most important KPI is stated to be the amount of received product per man-hour, referring to productivity. For put-away, the put-away cycle time is identified as most important. Regarding storage, the utilization of the storage space is argued to be most important, defined as the percentage of location and cube occupied. As for order-picking, the cycle time is identified as most important. Lastly, the most important KPI for shipping is the orders prepared for shipment per man-hour, referring to the shipping productivity (Kusrini et al., 2018).

Cai et al. (2009) discuss the interdependencies of KPIs in light of a framework for improving the iterative KPIs accomplishment in a supply chain context. The relationships between KPIs in the supply chain are complex. Cai et al. classify all measures identified in the supply chain into four categories: resource, output, flexibility, and informativeness. The KPIs of each category are all interdependent, and each category also has interrelationships (Cai et al., 2009). In addition to direct performance indicators, Staudt et al. (2015) discuss the indirect performance indicators that can be found in a warehouse. The indirect indicator themes are labour, value adding logistic activities, inventory management, warehouse automation, customer perception, flexibility, and maintenance. The indirect indicators require structured mathematical tools to calculate the value, not just a simple equations. Therefore, direct indicators typically form the basis for warehouse performance measurement (Staudt et al., 2015).

Lead vs. lag

Manuele (2009) discusses, leading and lagging indicators originate from the economics field. Leading indicators are used to predict changes in the economy. Examples of leading indicators are trends, building permits, inventory changes, and stock prices. Lagging indicators, however, measure changes after the economy has changed. Examples of such indicators are the employment rate, labor costs, outstanding bank loans, and inventory book value (Manuele, 2009). These indicators can be translated to other fields than just economics.

Anderson and McAdam (2004) discuss benchmarking and performance measurement. This can be translated to the idea of lead versus lag. Benchmarking is the continuous, systematic process of evaluating products, services, and work processes of organizations with the intention of organizational improvement. Lead benchmarking focuses on analysing predictive and future performance comparisons. This can enable organizations to develop core competencies and sustain competitive advantage. Lag refers to the traditional backward looking performance measurement systems. This implies identifying shortcomings and then arguing for change. Lag performance measures, compared to lead, lack strategic focus (Anderson & McAdam, 2004).

The lead versus lag concept can be translated to monitoring and prediction. While monitoring is the process of observing and checking the quality of processes, prediction is the process of trying to understand what will happen in the future.

Dreyer et al. (2008) discuss planning and control through real-time data. Planning and control is the act of facilitating an efficient and effective use of resources and assets, while producing and delivering products according to market demand and customer requirements. Traditional planning and control is typically performed on the basis of previous demand and event information. By implementing real-time data and accurate predictions of future demand and market developments in the planning, control, and decision-making, one can reduce uncertainty in the supply chain. Visualization and visibility of real-time demand makes information available to decision-makers (Dreyer et al., 2008).

3.2.5 Presentation of information for decision-making

With the incorporation of big data, there arises several opportunities for control and understanding of a warehouse. The WMS stores all the data one can need to understand how the warehouse operates, through tracking and storing big data. In order to use this to an advantage, one needs to translate the data so that it can be utilized by decision-makers.

Data visualization is a methodically developed graphic representing data in a manner that allows one to obtain insights, develop understanding, identify patterns, trends, or anomalies faster, and promote engaging discussions (Dasgupta et al., 2015). Data visualization involves presenting data in a graphical or pictorial form, making the information easier to understand (Sadiku, Shadare, Musa, Akujuobi, & Perry, 2016). Park et al. (2022) discuss the impact data visualization has on decision-making. They state that data visualization tools have the potential to support decision-making. Sadiku et al. (2016) introduce four visualization techniques: line graphs, bar charts, scatter plots, and pie charts. Visualization can bring advantages by increasing the amount of information delivered, as well as decreasing the cognitive and intellectual burden to interpret information for decision-making (Park et al., 2022). This fact is supported by Moore (2017), who states that one must apply sensory and cognitive processes to aid effective decision-making. Furthermore, Larose and Larose (2014) stress that information provides meaning to the decision-maker by correlating data within a context, ant that one needs to group information that has value or provides benefit to the decision-maker to achieve knowledge.

3.3 Storage location assignment

Once a storage strategy is selected, tactical decisions must be made, forming guidelines for the implementation is an operational problem. Gu et al. address three fundamental decisions that shape the storage function. Firstly, one needs to decide how much inventory should be kept in the warehouse. Secondly, the decision of how frequently and at what time the inventory for a SKU should be replenished need to be made. And lastly, one needs to decide where the SKU should be stored in the warehouse and it should be distributed and moved among the different storage areas. When looking into storage location assignment, there are several levels to consider. Gu et al. separate between the decisions of assigning SKUs to various storage departments and scheduling inventory moves between departments, decisions of assigning SKUs to different zones, and decisions of the storage location assignment within a department or zone (2007). This section focuses on the latter.

3.3.1 Storage system design

A type of load is typically referred to as en *item* or a *SKU* (Kay, 2015). All unique sizes, colors, or styles of an item are assigned a unique SKU. Each of these SKUs are stored in slots, also referred to as storage locations.

Kay (2015) discusses the design trade-off that needs to be assessed by every warehouse. The trade-off is between building and handling costs. To minimize handling costs, one wants to maximize the material accessibility, and minimize the expected distance from the inbound/outbound (I/O) port to the storage locations. One wants to have at least one unit for each item accessible for the picker, resulting in decreased cube utilization. Cube utilization is the percentage of total space required for storage which is actually occupied by the loads being stored. To minimize the building costs, one maximizes this cube utilization. This is done by minimizing perimeter length of a given area, minimizing the material accessibility. For warehouses mainly used for short term storage, handling costs usually dominate building costs. For warehouses used for longer-term storage, on the other hand, building costs typically dominate the design of the storage area (Kay, 2015). The decision regarding building costs and handling costs is referred to as a trade-off, as minimizing one of the costs will result in maximizing the other cost.

Storage locations

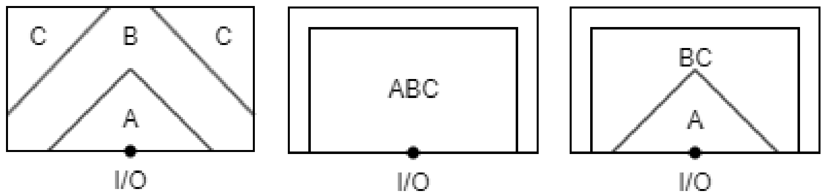
Every accessible storage location in a warehouse has a unique address (Kay, 2015; Bartholdi & Hackman, 2019). Storage locations are expensive, as they represent space, and carry the cost of rent, heating and/or AC, security, etc. (Bartholdi & Hackman, 2019). One can store items in several different storage mediums. Kay (2015) presents five different storage mediums: pallet racks, shelves, drawers, block stacking, and misc. locations. *Pallet racks* do not use compartment dimension. Only the front unit of each position is accessible for the picker. *Shelves* allow for all dimensions to be used if the compartment dimension is accessible. For *drawers*, the position dimension is not used if the drawer has odd shaped compartments. With *block stacking*, only the building, aisle, and bay dimensions are used to address each lane of storage. Lastly, *misc. locations* are the receiving areas, shipping areas, holding areas, outdoor trailer storage, etc., and can all be given unique addresses (Kay, 2015).

Kay (2015) introduce closest open location (COL), which is a policy that can be used for minimizing handling costs for units within a SKU. The policy entails retrieving units from the nearest available location. This policy works best when inventory is controlled and there is an approximate uniform rotation of items. Examples of uniform rotations are FIFO, FEFO, and LIFO. Uniform rotations are required when items are perishable (Kay, 2015).

Storage policies

Bartholdi and Hackman (2019) state that dedicated and shared storage are the main strategies used in storing product. For *dedicated* storage, each location is reserved for an assigned product. This means that only this product can be stored there. With a dedicated storage strategy, popular items can be stored in more convenient locations and workers can learn the layout, which can improve the efficiency of the order-picking. This strategy does not use space efficiently, as on average only about 50% of the space is utilized. *Shared* storage works to improve the utilization of storage capacity. This is done by assigning a product to more than one location. When one location is emptied, it is available for reassignment, meaning that a different product can be stored there. As one product is distributed to many storage locations, the location is emptied sooner, and the space can be recycled sooner. This strategy is generally more complicated to manage. Locations of products change over time, resulting in workers being unable to learn locations, making them dependent on the WMS for directions. The put-away becomes more time-consuming, as newly received products must be taken to several different locations. Since products are stored in several locations, workers may pick the product from a different location than they were meant to, causing discrepancies between book and inventory at two locations. Shared storage also requires greater software support and more disciplined warehouse processes. As shared storage provides efficient use of most of the space, while dedicated storage provides labor benefits, shared storage is typically used in bulk storage areas, while dedicated storage is used in the most active picking areas (Bartholdi & Hackman, 2019).

There are three different storage policies that are widely agreed upon: dedicated, randomized, and class-based storage (Kay, 2015; Lanza et al., 2022). The policies are presented in fig. 3.1.



(a) Dedicated (b) Randomized (c) Class-based

Figure 3.1: Storage policies
(Adapted from (Kay, 2015))

Dedicated storage places products classified as A closes to the I/O port, followed by products classified as B, and furthest away, the products classified as C (Kay, 2015). In short, the best locations are reserved for the products with the highest turnover (Silva et al., 2020). Kay (2015) states that the policy is also referred to as fixed slot storage, as each SKU has a predetermined number of slots assigned to it. As a result, the total capacity of the storage must equal the storage space corresponding to max on-hand inventory of each individual SKU. This policy minimizes the handling costs and maximizes the building costs. The storage is easily controlled, and each lane can be identified with a permanent label (Kay, 2015).

Randomized storage places all products, regardless of their classification, in one area (Kay, 2015). This policy is also referred to as open or floating slot storage. Each SKU can be stored in any available slot. The total capacity of all storage locations must equal the storage space corresponding to the maximum aggregate on-hand inventory of all the SKUs. Unlike *dedicated* storage, this policy minimizes the building costs, and maximizes the handling costs. It also makes it more difficult to control the storage, as the identity of a SKU stored at each slot needs to be recorded for retrieval purposes (Kay, 2015). An advantage of this policy is its simplicity (Silva et al., 2020).

Class-based storage combines dedicated and randomized storage (Kay, 2015). Products classified as A are placed closest to the I/O port, while B and C products can are placed in the same area. Silva et al. (2020) state that each class is dedicated to a zone, but within that zone, the locations are randomized. Building and handling costs are in-between that of dedicated and randomized (Kay, 2015). Classes can be formed from SKUs whose individual on-hand inventory is negatively correlated, or uncorrelated.

Classification

The storage policies classify the inventory items into categories in order to manage and control them separately. Such classification is called ABC-classification. The classification scheme is based on the Pareto principle, also referred to as the 80/20 rule (Yu, 2011). The 80/20 rule states that 20 percent of SKUs account for 80 percent of the activity (Bartholdi & Hackman, 2019). The categories of the ABC-classification, A, B, and C, are can be based on annual dollar usage, arranging inventory items according to the descending order of annual dollar usage (Yu, 2011). Bartholdi and Hackman (2019) present three other ways of classifying SKUs, the first being based on number of cases moved. The second is to rank the SKUs based on the number of times they were picked during an interval. The third method is to consider the number of pieces sold of each SKU. Brynzér and Johansson (1996) note that the classification can be performed based on the SKUs frequency.

Wild (2017), for instance, defines the rules for each category of ABC-classification as:

A: 10% of stock lines, giving 65% of turnover

B: 20% of stock lines, giving 25% of turnover

C: 70% of stock lines, giving 10% of turnover

Kheybari et al. (2019) define the category rules of conventional ABC analysis similarly, while also pointing to other measures important in inventory management. With the inclusion of multiple criteria, such as lead-time, obsolescence, and availability, the need to use multi-criteria decision-making methods to classify items arises. In addition to this, decision makers will use their experience, together with the results from the analysis, to determine the percentage of items related to each class, and rank them (Kheybari et al., 2019).

Independently of which method one uses to classify the inventory items, A items account for a small fraction of SKUs that account for the most activity, B items are moderately important, while C items are the bulk of SKUs that only account for a small portion of the activity (Bartholdi & Hackman, 2019). In context of the storage location assignment, the ABC-classification is used as a tool to analyse where each SKU needs to be placed according to their importance. As items classified as A have the highest turnover, minimizing their distance to the I/O port, and therefore minimizing their handling cost, will have a greater impact on the total handling costs than if the same were to be done for items of category B and C.

Muppani and Adil (2008) present the cube-per-order index (COI) as a criterion for assigning product classes to storage locations. This criterion captures both the item's popularity and its storage-space requirement. The COI of an item is defined as the ratio of the item's storage-space requirement to its popularity (number of storage/retrieval requests for the item). Muppani and Adil further explain how the items at a warehouse can be ranked by their COI, and thereafter grouped into product classes. The items belonging to the product class with lower COI values are placed closer to the I/O point, while the product classes with higher COI values are placed further away (Muppani & Adil, 2008).

Silva et al. (2022) state that there are three decisions that must be made regarding the classification of SKUs. The first is to decide the number of classes. The second is to decide the size of each zone dedicated to each class. Thirdly, one must decide the positioning of each zone in the warehouse (Silva et al., 2022).

Characteristics of items used for assigning location

When assigning items to a location or a zone, one base the decision on the item's characteristics. Brynzér and Johansson (1996) present frequency, size, weight, part number, and supplier as examples of characteristics used as a basis for this decision-making. Traditionally, SKUs are assigned to locations with respect to the characteristics of the items, typically based on their usage rates or turnover levels (Brynzér & Johansson, 1996).

Trindade et al. (2022) propose zoning SKUs based on their weight, and within these zones, fast-moving SKUs are located nearest the I/O port. Alternatively, they propose zoning the storage area based on frequency, and locating SKUs in descending order of weight, with the heaviest SKUs in the first aisle (Trindade et al., 2022). The zoning solutions require both information about the SKUs' physical characteristics, as well as classification.

3.3.2 Decision-making related to storage location assignment

One of the challenges in warehouse managerial decision-making regarding finding cost-effective strategies to reduce warehouse operational cost is defined as the storage location assignment (Ajol et al., 2018). Decisions made in relation to the storage location assignment will not only affect the operation cost, but also the warehouse performance. While Gu et al. (2007) state that decisions related to storage location assignment are operational, M. Wang et al. (2020) state that the storage location assignment is a tactical decision.

Reyes et al. (2019) state that the storage location assignment concerns the allocation of products into a storage space and optimization of the material handling costs or storage space utilization. Storage location assignment depends on several parameters, varying from problem to problem. These typically include storage area design, storage space availability, warehouse storage capacity, physical characteristics of the products, arrival times, and demand behavior (Reyes et al., 2019).

Brynzér and Johansson (1996) introduce two policies focusing on the storage location assignment, with the aim of making the picking process more effective. The first policy focuses on the assignment problem, which concerns the allocation of the SKUs to specific locations. The second policy considers the assignment of the SKU as given. It focuses on choosing the most similar orders together in a batch. The objective of this policy is to group orders in a way that reduces time spent on travel, reading info, and other activities that could be shared between orders more efficiently than if randomized order selection were used (Brynzér & Johansson, 1996). Kay (2015) state that for some warehouses, it is advantageous to store product by product family, such as according to retailer's storage locations. If the products that are displayed together in-store are stored together in-warehouse, they will likely be picked on the same pallet, reducing the work to shelve product at the retail store (Kay, 2015).

There is a unanimous agreement in the industry that fast-moving SKUs should be stored in the most convenient locations (Bartholdi & Hackman, 2019). This is one of the efforts made with the objective of minimizing travel time. Brynzér and Johansson (1996) also points to the importance of storing components that are likely to appear together on an order in close proximity to each other. Another factor to consider, regarding order-picking, is the weight of the products. Kay (2015) states that one should place heavy items so that they will be picked first, ensuring that the finished pallets are stable and do not damage lighter items.

Courtin et al. (2020) state that product characteristics such as weight and dimensions are highly important when considering storage location assignment. Furthermore, the dates of entry and exit of each product at the warehouse is used as input. In addition to these inputs, Courtin et al. state that there are two factors that are often overlooked when considering storage locations. Firstly, the fact that a SKU's frequency of demand and quantity in pick orders can vary and fluctuate over time. The second factor often overlooked is the arise of rare, but significant, events, such as campaigns leading to a sudden and brief peak in demand (Courtin et al., 2020).

The use of mathematical models for storage location assignment

The term storage location assignment problem (SLAP) is typically used when storage location assignment is handled through mathematical models. Gu et al. (2007) define the SLAP through inputs, an objective, and constraints. The inputs are given as:

1. Information on the storage area, including its physical configuration and storage layout.
2. Information on the storage locations, including their availability, physical dimensions, and location.
3. Information on the set of items to be stored, including their physical dimensions, demand, quantity, arrival and departure times.

The objective of the SLAP is to determine the physical location where arriving items will be stored (Gu et al., 2007).

The performance criteria and constraints of the SLAP, defined by Gu et al., are:

1. Storage capacity and efficiency.
2. Picker capacity and efficiency based on the picker cycle time.
3. Response time.
4. Compatibility between products and storage locations and the compatibility between products.

5. Item retrieval policy such as FIFO, LIFO, batch first-in, first-out. When using the batch first-in, first-out policy, items that arrived in the same replenishment batch are considered to be equivalent.

Choy et al. (2017) present a model for the SLAP in a radio frequency identification (RFID)-based storage system. They utilize two modules, one for data collection and one for decision support. The data collection module captures SKU related data critical for the SLAP. This includes data on the SKU's dimensions, weight, loading values, etc. The data is stored in a centralized database, linked to the internal systems WMS, ERP, and customer relationship management. The central database works as a bridge between the two modules. The decision support module applies fuzzy logic to assign each SKU to an appropriate storage location. The fuzzy rules are evaluated regularly to ensure data quality determined by the system. Monitoring results from the RFID readers are used to refine the fuzzy rules (Choy et al., 2017).

Muppani and Adil (2008) use a simulated annealing algorithm for formation of storage classes. To decide storage assignment and class formation, the model solves an integer programming model. The model considers all possible product combinations, storage-space cost, and order-picking cost. Furthermore, they use COI to order items (Muppani & Adil, 2008).

Ajol et al. (2018) use a mixed integer programming model for class-based storage location assignment. This is combined with a COL policy. The model considers volume of storage space used to maximize storage space utilization. The assignment of products to product classes is performed through ExCeL. The model is compared to a dedicated storage policy, finding that the developed model using a class-based storage assignment policy resulted in cost reduction (Ajol et al., 2018).

Calzavara et al. (2019) present a model for the SLAP of a low-level order-picking warehouse, considering cost and ergonomic indicators. The picking from the pallet rack alternatives are evaluated by the workload and the worker posture index. The SLAP uses a heuristic procedure. The procedure is compiled by methods for evaluating different rack layouts. For each storage location assignment, one can calculate the average total cost, energy expenditure, and the worker posture index value per order. The model can be used as decision support for managers as a tool to assess ergonomic conditions for order-picking. The model considers both the economic and ergonomic impact of a warehouse layout, as well as the cost of ergonomic interventions, such as the managers decision to redesign the rack and storage configuration (Calzavara et al., 2019).

Ahmed et al. (2021) present a multi-criteria mathematical model and a priority-based heuristic approach for the SLAP. The mathematical formulation accounts for a set of criteria, including inbound locations, outbound locations, location in network, ABC-classes, demand patterns, and enumeration of all possible routes. The formulation also includes several parameters: requirement for dry space, capacity of warehouse, demand requests, storage time of product, and order list per combination of attribute values. The problem cannot be solved exactly, which is why they introduce a heuristic approach (Ahmed et al., 2021).

Heragu* et al. (2005) present a mathematical model and a heuristic algorithm for determining product allocation to the reserve storage area, forward area, and cross-docking in a warehouse. The model additionally determine the optimal size of each area, using data readily available to a warehouse manager. The model assumes a set of statements: available total storage space is known, expected time each product spends on the shelves is known, cost of handling each product in each flow is known, time spent on the shelves and cost have a linear relationship, annual product demand rates are known, and storage policies and material-handling equipment are known. The model allows the user to solve the two problems simultaneously, given a set of constraints (Heragu* et al., 2005).

Dynamic storage location assignment

In dynamic warehouse environments, the material flow changes due to factors such as seasonality or short shelf life of the products (Chen et al., 2011). For dynamic warehouse environments, a static approach to the storage location assignment may be inefficient. Dynamic storage policies entails that the SKUs are not assigned permanent locations (Aasheim & Cherrie, 2022). This leads to the need for relocation of products, which is the movement of an item from one storage location to another storage location (Chen et al., 2011). This approach opens for the possibility to move a product closer to the I/O port only in periods of peak demand, and further away when the demand is lower.

Aasheim and Cherrie (2022) discuss the benefits and challenges of dynamic storage location assignment, while introducing the addition of reshuffling goods. The key benefit from implementing dynamic storage location assignment is identified as the ability to strategically update storage locations based on volume and demand. This can lead to an increase in warehouse efficiency and large savings in travel time due to an increase in efficiency of order-picking. The challenges of of dynamic storage location assignment is connected to the increased complexity compared to static storage location assignment. It is both time- and resource-consuming to update storage locations. In order to update storage locations, one also requires more information about demand and volume to support the decisions of where to move the product. An example of this, is the need for accurate forecasts (Aasheim & Cherrie, 2022).

The reshuffling of goods, as discussed by Aasheim and Cherrie (2022), must be implemented in combination with a dynamic storage policy. Aasheim and Cherrie argue that reshuffling can further improve the benefits of a dynamic policy, as it opens up for the relocation of goods already located in the warehouse, not only new incoming goods. They further suggest utilizing idle time for this process, improving workload balance. Challenges regarding the reshuffling of goods are related to the further increase complexity of the planning. It raises the question of how, when, and where to preform the reshuffling. This requires information about future demand, and for the occurrence of idle time to perform the reshuffling without taking away from the warehouse productivity (Aasheim & Cherrie, 2022).

Aasheim and Cherrie (2022) present suggestions for how to decide when to perform reshuffling of goods. The first suggestion is to analyse the picking pattern. This requires data on the layout and transactions. Layout data includes maps or overviews of the warehouse, information about racks, shelves, and bay numbers, distances, and dimensions of shelves. For the WMS's transaction data, one needs information about registered activities regarding picking, put-away, movement of items, and packaging, date and time of scanning, amounts, article numbers, client numbers, location of the transactions, etc. Furthermore, they provide two methods for plotting the picking data. The first method is to plot the amount of picking for different areas in the warehouse, and the second is to plot the amount of each picking process (Aasheim & Cherrie, 2022).

Secondly, Aasheim and Cherrie (2022) suggest a demand pattern analysis. The intention of the analysis is to reveal when it is most beneficial to reshuffling, and when to focus on which items. For this analysis, one needs time related data on forecasts and transaction data. Forecasts provide information about future sales orders, and can imply when reshuffling should occur and for which products. It provides insight of low and high activity periods, and predictions for which products have high and low demand at what time. The transaction data required from the WMS is historic transaction, used to identify demand patterns and trends, analyzed with respect to time, not place. The results are proposed to be plotted either by amount of picking per time period, or amount of picking per time period for different SKUs (Aasheim & Cherrie, 2022).

In addition to picking pattern and demand pattern analysis, Aasheim and Cherrie (2022) discuss reshuffling method analysis. This entails the decisions on how to perform the reshuffling and evaluate the performance of different reshuffling methods. For this, one needs data on layout, equipment, and capacity. Layout data includes information on distances and dimensions, which is necessary for estimating travel time. For the equipment data, one requires data on speed of trucks and capacity of the equipment to calculate travel time. Lastly, to identify idle time and decide which operator should perform reshuffling, one needs information about the capacity (Aasheim & Cherrie, 2022).

The storage location assignment studied in the literature is most often static (Gu et al., 2007). In reality, the problem is not static, but dynamic, as the material flow is due to change because of factors such as seasonality and life cycles of products. This argues for the need for relocations.

Gu et al. (2007) list problem statements regarding the dynamic storage location assignment and method for solving it - heuristic, rule of thumb, optimal ranking, etc.

Strategic, tactical and operational decisions

Based on the literature from this section, there are both strategic and tactical decisions which affect the operational decisions related to storage location assignment. The strategic decisions are long term, and state what the overall aim of the warehouse is. They are highly influenced by which approach the company chooses for the trade-off between handling and building costs, and apply the guidelines for daily decisions at the warehouse. The strategic decision areas are listed in table 3.5.

Table 3.5: Strategic decisions affecting storage location assignment

Decision area	**Description**	**Sources on the topic**
Warehouse layout design	Determining overall layout and configuration of the warehouse	Bartholdi and Hackman (2019), Kay (2015)
Storage system design	Choosing the appropriate storage systems for the inventory, space utilization requirements, and handling costs. Includes decisions regarding pallet racks, shelving, retrieval systems, etc.	Bartholdi and Hackman (2019), Kay (2015)
Storage policy	Before deciding specific storage locations for the SKUs at a warehouse, one needs to decide which storage policy to implement. Through dedicated storage policies, each SKU is dedicated to one storage location, and no other SKU can be placed in the same location. With a shared storage policy, SKUs can be assigned to several storage locations.	Bartholdi and Hackman (2019), Kay (2015), Silva et al. (2020), Lanza et al. (2022)
Static vs. dynamic	Decision-makers must evaluate the importance of moving SKUs to accommodate any fluctuations in demand (dynamic) versus keeping SKUs in permanent locations (static).	Chen et al. (2011), Aasheim and Cherrie (2022), Gu et al. (2007)

To achieve the objectives of the strategic decisions, one needs to make tactical decisions. These decisions are made with a focus on medium term considerations, such as inventory management. The tactial decisions related to storage location assignment are listed in table 3.6.

Table 3.6: Tactical decisions affecting storage location assignment

Decision area	Description	Sources on the topic
Classification	Need to decide number of classes, the size of each zone for each class, and each zone's position in the warehouse. The classification is used as a tool to locate important SKUs in favorable locations. Two approaches to classification are ABC-classification and classification based on the SKUs' COI.	Silva et al. (2022), Silva et al. (2020) , Yu (2011), Bartholdi and Hackman (2019), Brynzér and Johansson (1996), Kheybari et al. (2019), Muppani and Adil (2008)
Zones	Decision-makers must choose whether or not to implement zones, and which zoning to implement. The zones can be related to the classification of products, product groups, or the product's physical characteristics.	Gu et al. (2007), Silva et al. (2020), Silva et al. (2022), Trindade et al. (2022), Brynzér and Johansson (1996)
Product groups	The warehouse can group products different ways, which entails locating SKUs of a product group in close proximity to each other. One can group products based on whether they are frequently ordered together or based on the product family, which is common for warehouses in the retail supply chain.	Brynzér and Johansson (1996), Kay (2015)
Location of heavy items	Decision-makers should locate heavy SKUs where the order route typically starts, for efficient order picking.	Brynzér and Johansson (1996), Kay (2015)

Lastly, there are the decisions made to implement the tactical and strategic visions. These are the operational decisions, which focus on the short term considerations. While the operational decisions visit the same decision areas as the strategic and tactical decisions do, the decision-makers approach them differently. The strategic decisions are made on a long term level, guiding medium term and daily decisions. The operational decisions are more specific, approaching the decision area at an item specific level. Table 3.7 summarizes the identified operational decision areas for storage location assignment.

Table 3.7: Operational decisions associated with storage location assignment

Decision area	Description
Classification	Deciding which class each SKU belongs to based on the demand at the time.
Zones	Assigning SKUs to storage locations within the zone which their physical characteristics demand.
Product groups	Placing SKUs in product groups based on the criteria for each product group and the SKUs' physical characteristics.
Location of heavy items	Using information about the SKUs' weight to decide where to locate the SKU in the forward area.

Table 3.8 summarizes the information needed to make operational decisions regarding storage location assignment.

Table 3.8: Information needed for decisions associated with storage location assignment

Decision area	**Information for decision support**
Classification	Demand characteristics Campaigns Customer orders
Zones	SKU-specific attributes
Product groups	SKU-specific attributes Customer orders
Location of heavy items	SKU-specific attributes

3.4 Summary of theoretical background

This section summarizes the key findings from the theoretical background, focusing on the storage location assignment.

- Travel time is highly affected by SKUs' storage location assignment. To reduce the travel time, one should store SKUs in convenient locations. When prioritizing SKUs' storage locations, one should place fast-moving SKUs in the most convenient locations, to minimize travel time.
- There are several ways to approach storage location assignment. One approach to the storage location assignment is to group items based on whether they are frequently ordered together. Another approach is to group items based on which product family they belong to. Placing products of the same product group in close proximity to each other can reduce travel time.
- When referring to the SLAP, one typically refers to the optimization problem of storage location assignment. Solving this problem is complex. The use of mathematical models typically require heuristic approaches, or the use of fuzzy logic, as they are difficult or even impossible to solve exactly.
- Dynamic storage location assignment entails that SKUs are not assigned permanent storage locations. The dynamic approach applies to warehouses with a dynamic material flow. SKUs are relocated to accommodate the demand for certain time periods at a time.
- The relocation of SKUs can decrease travel time, as it considers the optimal storage locations for the current material flow. A dynamic storage policy also increases the complexity of the storage location assignment, and is both time- and resource-consuming.

- The reshuffling of product builds on a dynamic storage policy. It adds the option of moving product which is already in inventory. This further adds to the benefits of a dynamic policy, while also further increasing the complexity and the time and resources necessary.
- To make informed decision in a specific situation, one needs to know which data is necessary to make decisions in that situation. Access to big data will not automatically improve decision-making. One also needs the right tools to utilize the data, and know which data is useful which decision area. The decision-maker's experience and knowledge affects how well the big data can be used for quality decision-making.
- Data visualization is a tool for making data understandable for decision-makers. Visualization can come in many forms, and must match the information that one wants to convey. The use of data visualization can increase the amount of information delivered to decision-makers, and decrease the burden of interpreting raw data.

4 Warehouse Management Systems (WMS)s

This chapter provides theoretical background to WMSs. Firstly, general information about WMSs is presented, followed by a brief introduction to common functionalities. Furthermore, the use of big data in the WMS is introduced. Lastly, the WMS's role in storage location assignment is explored, before summarizing the challenges and opportunities of the WMS in storage location assignment.

4.1 Introduction to WMSs

An aspect of warehouse operations is warehouse control (Kay, 2015). Warehouse control includes the inventory control and storage management. The software system, warehouse management system (WMS), enables real-time data and paperless control of operations (Kay, 2015). Nettsträter et al. (2015) state that the business of the WMS is the operation and optimization of on-site warehousing systems. Bartholdi and Hackman (2019) define a warehouse management system (WMS) as a complex software package that helps manage inventory, storage locations, and workforce. Additionally, Hamdy, Mostafa, and Elawady (2018) state that the information system integrates software systems to monitor, control and manage quantities and optimize warehouse decisions. For example, the system interfaces with the ERP software, and information is used to create and maintain an inventory and location master file (Kay, 2015). The system is used alongside control logic, with the intention of executing warehouse operations. Additionally, the system interfaces with various automated material handling equipment systems, and generates picking orders for order-picking (Kay, 2015).

The WMS's purpose, as stated by Bartholdi and Hackman (2019), is to ensure that customer orders are picked quickly, packed, and shipped. The WMS knows about every item in the warehouse. This includes physical dimensions, how it is packed by the vendor, all storage locations in the warehouse, their address and physical dimensions. The WMS can orchestra the flow of people, machines, and product. When the WMS receives a customer order, it transforms them intro pick list organized for easy retrieval. Items in the customer orders appear in an arbitrary sequence. The WMS acquires several responsibilities. The first is the inducting of newly arrived products, allocating them to available locations. The second is coordinating the assembly of customer orders to meet shipping schedules. Thirdly, the WMS tracks productivity of workers. The WMS can also communicate with other specializes software, such as yard management systems, which coordinates movement of full and empty trailers in the yard. Lastly, the WMS may provide a summary of data to an even larger supply chain management (SCM) system, which plans and coordinates inventory levels and transportation from manufacturer to customer. Systems like WMSs are the reason for the control that has caused an acceleration of the pace of the supply chain over the last 20 years or so. Precisely controlled product moves faster, leading to better customer service and less inventory in the system (Bartholdi & Hackman, 2019).

Bartholdi and Hackman (2019) state that as of 2019, there are over 300 WMS vendors in the US alone. Grand View Research offers a report on the global WMS market (*Warehouse Management Systems Market Report, 2030*, 2023). The global market size value in 2023 is USD 3.94 billion, with an expected growth of 19.0% from 2023 to 2030. Some of the most prominent vendors of the WMS market are EPICOR, Manhattan Associates, PSI Logistics, and SAP. Europe holds the largest market share with over 31.49% of the global revenue share (*Warehouse Management Systems Market Report, 2030*, 2023).

4.2 Functionalities

The WMS consists of several functionalities available to the user. While the system provides a set of elementary functionalities, there is an increasing demand for extending the functionalities (Bartholdi & Hackman, 2019; Nettsträter et al., 2015; Hamdy et al., 2018). The elementary functionalities, as stated by Nettsträter et al. (2015), are managing quantities and storage locations, controlling and scheduling the means of transport, comprehensive methods and instruments to supervise the system's status, and selection of operating and optimizing strategies. Bartholdi and Hackman (2019) note that the essential financial transactions are related to the functionalities involving receiving and shipping. Furthermore, they state that the ability to manage an inventory of stock locations in addition to inventory of product, supporting warehouse operations, is managed through the stock locator system functionality. Hamdy et al. (2018) state that the key functions of the WMS are order processing, order release, and master data, while extended functions are receiving, put-away, and warehouse control. The WMS typically provides a menu of features (Bartholdi & Hackman, 2019). This includes long lists of basic, high-end, and advanced features of a WMS.

As previously stated, there is an increasing demand for extending the functionalities of the WMS. Vendors of WMS's constantly enlarge the scope of their functionalities to suit customer demands (Nettsträter et al., 2015). The aim of enlarging the scope of functionalities is to further cut costs for the customers' warehouses. Further functionalities of the WMS, which are now considered standard functionalities, include the planning of tours and routes, support of vendor managed inventories, or the support of billing and value added services in case of multi-client scenarios (Nettsträter et al., 2015). Furthermore, Bartholdi and Hackman (2019) introduce supply chain execution systems. This points to the extending of the WMS functionalities along the supply chain, both upstream and downstream, including features that support collaboration. Nettsträter et al. (2015) support this, stating that WMSs increasingly offer functionalities with their origin in ERP software, supply chain management (SCM) software or transport management system software. This increases the support of all processes between receiving and shipping (order fulfillment) and comprehensive information systems and control panels.

Warehouse Management Systems - Where to Start? White Paper (n.d.) presents an overview of typical characteristics and functionalities found in WMSs of different levels of complexity. This is presented in table 4.1

Table 4.1: Characteristics and functionalities of WMSs depending on its complexity (Adapted from *Warehouse Management Systems - Where to Start? White Paper* (n.d.))

Complexity	Example Functionality	Key Characteristics
Level 1	The most basic functionality, often without location tracking	Inventory management and control are secondary processes Manual processes with minimal use of technology Typically use whatever capabilities provided by ERP or manual processes
Level 2	Stock location, put-away, inventory management routines, basic user productivity management, basic reporting	Focus on execution Minimal complexity with typically rudimentary needs for product locating for put-away, picking and packing Focus on simple storage and retrieval Some radio frequency activities, but often aspects are paper based or off system
Level 3	Comprehensive order management (e.g. palletisation), multiple receiving, put-away and pick strategies including directed wok assignments, self service reporting	Increased WMS capability, but still focused on process execution End to end coverage of warehouse processes Extensive use of radio frequency or voice for execution Focus on improving warehouse task execution performance
Level 4	Order streaming, task interleaving, multi customer picking, labor management, dock scheduling, yard management, adaptable architecture	Focus moves more towards warehouse productivity, efficiency, and throughput rather than just execution Utilised in facilities handling more demand, typically with more users, which need for decision support and extended WMS capabilities
Level 5	Highly mature material flow adapters, generic support for automated storage and retrieval systems, pick to light, goods to person, bulk pick to belt as standard	Seen in highly automated sites, where warehouse and automation design are often done in conjunction These types of facilities are highly automated with the automation intrinsically woven into warehouse processes

Depending on which WMS one chooses, there are several available functionalities which can aid the warehouse with inventory control. Regarding storage location assignment, the functionalities that can aid decision-making should hold information about stock locations.

4.3 Big data

The functionalities of a WMS are possible through the collection, processing, and analysis of big data (Hamdy et al., 2018). Srividya and Tripathy (2022) define big data as data with large volume, whose growth is exponential in nature. Big data cannot be handled by traditional data handling techniques (Srividya & Tripathy, 2022), and therefore require specialized systems. One typically characterize big data by the four V's: volume, variety, velocity, and veracity (Srividya & Tripathy, 2022). (Jeble, Kumari, & Patil, 2017) state that there are five V's of big data, adding value as the fifth characteristic.

Furthermore Srividya and Tripathy (2022) discuss the use of big data in warehousing. They state that big data can be used to help a firm in choosing the right option for the warehouse through increasing cost efficiency while satisfying the other criteria. To use big data as support for decision-making, it needs to be converted into information that decision-makers can understand (Hamdy et al., 2018). Big data analytics can help future staff recruitment or shift staff between warehouses to balance the work load efficiently (Srividya & Tripathy, 2022). Through merging real time data with ERP and WMS, one can potentially identify any additional waste in the warehouse process.

5 Empirical Background

This chapter poses as an empirical context to the study. The characteristics of fast-moving consumer goods (FMCG) and the FMCG industry is explored to provide background information for the case study.

5.1 Fast-moving consumer goods (FMCG)

The FMCG industry is characterized by its quick turnover and agility (Bala & Kumar, 2011; Karthik & Prasad, 2020), and is one of the largest industries in the world (Bala & Kumar, 2011). Jacobs and Mafini (2019) define FMCG as items that are sold quickly and usually at a low price to a large customer base. Due to the rapid consumption and high demand of FMCG, the product is usually produced in large volumes. Examples of segments of FMCG are personal care packaged food and beverage, and household care (Bala & Kumar, 2011). The products are also typically subject to variable demand, and are effected by factors such as seasonality. This calls for the need for warehousing to be able to meet demand on time.

5.2 The FMCG supply chain

Manders et al. (2016) present an overview of a typical FMCG supply chain. The supply chain starts with the supplier, supplying products or raw material to either a logistics service provider, or straight to the manufacturer. From there, product is transported to the the logistics service provider. The logistics service provider typically has responsibility of all warehouse operations, logistics, and distribution services, undertaking the picking and packing of outgoing flows. From here, the product is delivered to the retailer (Manders et al., 2016).

Companies operating in the FMCG supply chain can be subject to the bullwhip effect (Bala & Kumar, 2011). The bullwhip effect is a phenomenon where order variability increases as the orders move upstream in the supply chain (X. Wang & Disney, 2016). This can occur with regard to the difficulty in predicting demand for FMCG, with its variable demand and subject to seasonality and campaigns, as well as the communication between production, logistics service providers, and retailers.

FMCG, such as food, can easily be substituted with similar products by the consumers (Basson et al., 2019). As FMCG organisations therefore trade primarily on volume, it is considered equally problematic to not meet demand as to have excess demand. CieChańska (2018) states that production companies within the FMCG industry practice make-to-stock. This entails that warehouses are used to store the inventory necessary to meet demand.

Food is one of the segments of FMCG. This segment is one in need of further considerations, with the added factor of perishability. The food supply chain is characterized by changing and variable consumer and governmental demands (Trienekens et al., 2012). The need to satisfy these demands results in high complexity of the supply chain. A typical food supply chain start with producers who supply raw materials, packing material, etc. to the food production company in question (Romsdal, 2014). The food production company receives the necessary raw material, process them, and pack them for transportation. The finished products are distributed to wholesalers, who further distribute the products to retail stores. The retailers fill their shelves and sell the products to the end consumer (Romsdal, 2014).

Products within the food supply chain are characterized by their perishability, complexity, variety, programmable logic controller, and volumes (Romsdal, 2014). The market is characterized by delivery lead time, demand uncertainty, and inventory management. The production system characteristics are described by production lead time, production processes and technology, and supply uncertainty (Romsdal, 2014).

Characteristics of the food processing industry, categorized into characteristics of the plant, product, and production process, are listed in table 5.1. The food supply chain is also characterized by the product and market, and the process and stock (Donk, 2001). The requirements of the food market are short delivery times and high reliability. The demand of the food market is irregular and unpredictable, and specific products are expected. The process is constrained by long lead times and bad process control, and the inventory demands low stock levels and the need to reduce risk of outdated products (Donk, 2001).

Table 5.1: Characteristics of the food processing industry (based on Donk (2001))

	Characteristics
Plant	Flow shop oriented design, expensive, single-purpose capacity, small product variety, and high volumes. Long, sequence-dependent set-up times between different product types.
Product	Variable supply, quality, and price of raw material. Volume and weights are used (in contrast with discrete manufacturing). Raw material, semi-manufactured products, and end products are perishable.
Production process	Processes have varying yield and processing time. At least one of the processes will deal with homogeneous products. Processing stages are not labor intensive. Production rate is mainly determined by capacity. Divergent product structure, especially in the packing stage. Consumer goods may lead to extensive, labor intensive packing phases. Uncertainty in pricing, quality, and supply of raw material lead to several recipes available for each product.

One of the main challenges in the food sector is that market demands are insufficiently communicated throughout the supply chain. As Trienekens et al. (2012) state, perishable products have a major role in our economy.

5.3 Customer demand

Arnold et al. (2008) define demand as something that shows the need for a product. While supply is defined as the quantity of goods that sellers offer, the demand is the number of consumers willing to purchase said goods for the given price (Thompson, 2010). Participants who affect the supply of a product are the manufacturers, the distributor, and the consumer. The demand on the other hand, is purely determined by the consumer (Thompson, 2010). Demand is therefore a result of all the attributes affecting the consumer's habits, and thereby their wish to purchase a product.

5.3.1 Attributes of demand

Arnold et al. (2008) introduce three characteristics of demand: demand patterns, stable versus dynamic, and dependent versus independent. Knowledge of these characteristics of demand is critical when attempting to predict demand.

A *demand pattern* shows how demand varies from period to period, when plotting historic data for demand (Arnold et al., 2008). Attributes contributing to this pattern are trend, seasonality, random variation, and cycle. *Trend* indicates whether demand is linear, geometric, or exponential, and whether the demand is level, rising, or falling from year to year. *Seasonality* indicates fluctuations as a result of weather, holiday seasons, or seasonal events. *Random variation* is when demand is affected during specific periods and on a random basis, as a result of many factors. When plotted, this attribute shows up as points that deviate from the demand pattern, either close to the pattern or widely scattered, depending on the size of the variation. The *cycle* shows how the increases and decreases in the economy influence demand (Arnold et al., 2008).

Depending on how the demand pattern presents over time, it can be considered either *stable* or *dynamic* (Arnold et al., 2008). A *stable* demand maintains the same general shape over time. Demand is *dynamic* when the demand pattern changes trend, seasonality, or randomness. *Stable* demand is easier to forecast than *dynamic* (Arnold et al., 2008).

Independent demand is classified as products that are not related to the demand of other products (Arnold et al., 2008). Demand is *dependent* when the demand of a product is derived from the demand of a second product. Only products with *independent* demand needs to be forecasted (Arnold et al., 2008).

FMCG are characterized by a large customer demand (Nemtajela & Mbohwa, 2017). Attributes that typically affect the sales of food are campaigns, advertising, weather, seasonal patterns, trend, weekday versus weekend purchases, price variations, substitutions, and public holidays (Kao & Chueh, 2022; Sukhochev, 2021; Arunraj, Ahrens, & Fernandes, 2016). The several attributes of demand for FMCG result in a complex supply chain. To control the supply chain accordingly to the demand, one needs demand forecasting. As the sales of perishable products are expected to increase, controlling the inventories of the products are of increasing importance (Bašljan et al., 2021). Consequences of not predicting may result in waste or not being able to meet demand, both leading to loss of revenue.

6 Case Study

This chapter investigates the case of a company that utilize the WMS supplied by Solwr. The case company of the case study is the Norwegian grocery chain company. Firstly, the case company is introduced, followed by an explanation of Solwr's WMS. Furthermore, the case company's warehouse and their warehouse operations are described, followed by an analysis of their operations. The analysis focuses on the storage location assignment and their use of the WMS for decision-making. Lastly proposals for improvements are presented and discussed.

6.1 Introduction

This section introduces the two actors in the case study: the case company and Solwr. The case company provides insight of storage location assignment at a warehouse, and how Solwr's WMS is used for decision-making. Solwr provides information about their system's features and functionalities.

6.1.1 Introduction to the case company

The case company operates in the FMCG industry. The object of the study is one of the company's retail distribution centers. The warehouse is the between suppliers and retail stores. These types of distribution centers are subject to large volumes of products, and only store products temporarily before they are picked by orders and shipped to the customers. A general distribution supply chain for these type of warehouses is illustrated in fig. 6.1

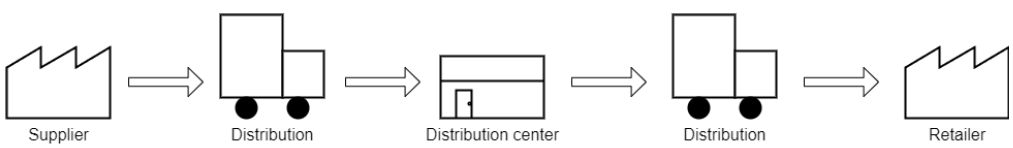


Figure 6.1: Retail distribution center supply chain

The case company has a large quantity of suppliers. The warehouse mainly picks up deliveries at the suppliers' location, with few exceptions. They experience over a thousand pickups per week, and send around 100 trucks every day. At the distribution center, they order, receive, control, and readies products for order-picking. From the customers, they receive orders, pick the orders, load trucks for distribution, and distribute products to the retailers. The distribution center keep approximately 1000 employees. For distribution, the case company both use their own trucks, as well as rented trucks. The frequency of deliveries is customized to each retailer's volume. Every week, the distribution centers make approximately 3500 deliveries. The retailers' tasks include ordering, receiving, and controlling products. Received product is placed either in store shelves, or in inventory. Any deviations from deliveries are reported and followed up.

As the company operates within the FMCG industry, and handles perishable goods. FMCG are characterized by their quick turnover, and with the perishability factor of some of the products, the warehouse experience the added complexity of the products' short shelf life. There are high demands for quality, timeliness, and safety when handling the product. The warehouse distributes products to over a hundred retail stores. The warehouse distributes thousands of pallets, hundreds of thousands cartons, and hundreds of deliveries every week to the retailers.

6.1.2 Introduction to Solwr

The warehouse is one of Solwr's customers. Solwr is a company working to optimize trade logistics. The company supplies warehouses with a WMS for control of inventory and warehouse operations. The WMS that Solwr provides is called Trace. This system provides the warehouse with several features supporting all warehouse operations.

6.2 The case company's warehouse and warehouse operations

This section describes how the case company's warehouse is organized and how it operates, focusing on how they assign SKUs to storage locations.

6.2.1 Warehouse layout

The warehouse is separated into three areas: one for dry goods, one for fresh goods in need for cooling, and one for frozen goods. The dry area has two receiving areas, one in each end of the area. This is with the aim of reducing travel distances for the trucks in the put-away process. The chilled and freezing area each has one receiving area.

The warehouse uses racks for storing of pallets. For the manual racks, single-deep lanes are used for accessibility for the order-pickers. Double-deep lanes are used where the automatic cranes operate, as accessibility for pickers is not a contributing factor. The warehouse follows the typical layout of a forward area as that of a carton-pick-from-pallet area. The forward area is mainly on floor level, also utilizing the second level of the racks when necessary. Ideally, the forward area would be limited to the floor level, but due to storage limitations and the high volume of SKUs at the warehouse, two levels of the rack must be used as forward area. Each SKU has a unique pickup location in the forward area. The location is marked with an address and a control number, used for order-picking through pick-to-voice. The reserve area starts at the third level of the racks. The WMS aims to place SKUs in the reserve area in immediate proximity to the same SKU's pickup location. The ideal placement is directly above the SKU's pickup location. This is not possible for all the SKUs, due to storage limitations and the high volume of SKUs in the warehouse.

6.2.2 Warehouse operations

The warehouse practices a first-expired, first-out (FEFO) rotation of product, to avoid excessive waste due to expiration of products. In general, products that enter the warehouse first will be the first to be picked from the warehouse. In certain cases, however, newly arrived products' expiration dates are closer in time than those already on hand. With the FEFO rotation, this is taken into consideration. The put-away and order-picking processes at the warehouse are mainly manual. All single-lane racks are used for manual put-away and order-picking. The three automatic cranes at the warehouse operate in the double-deep racks. The cranes can process 60 movements per hour each, and are prioritized for high frequency goods.

Receiving

The receiving area at the warehouse is open for deliveries from 07.00 to 16.00 every day. in-coming products at the warehouse are mainly delivered in pallets. In addition to the dry, chilled, and frozen goods to be stored in the warehouse, they receive pallets for cross-docking from other companies. If deliveries arrive outside this time frame, the warehouse makes the decision of whether to accept the delivery depending on excess capacity at the time. How many goods the warehouse receives depends from day to day. Delivery volumes can vary from a few hundred to 2500 pallets every single day. The daily material movement at the warehouse varies from day to day. There is, however, general structure of which days have the most movement. Mondays and Tuesdays are typically busy days, slowing down on Wednesdays, before it gets busier on Thursdays again. Fridays are the slowest at the warehouse.

Upon receiving products, every pallet is checked to ensure that the correct quantity is received, and that there are no damages to the pallets. This is done manually, and any deviations are reported and followed up. In the receiving area, pallets are stored temporarily before they are picked up by trucks or by the automatic cranes, and transported to the reserve area or directly to the forward area. Pallets are received as full pallets, containing exclusively cartons of the same SKU.

By the receiving area, there is also a cross-docking area. This area stores product that goes straight from receiving to shipping. The product in this area is brought to the warehouse for distribution efficiency purposes. The pallets are assigned trucks that have excess available space on their route to delivery. The warehouse receives approximately 100 pallets every day for cross-docking. Some pallets are readily packed for the customers, while other pallets may need to be recompiled, if they contain cartons going to different customers.

Put-away

The put-away process is mainly performed manually. Experienced workers are in charge of placing pallets higher up in the racks, as this is more difficult than handling pallets closer to floor level. Received goods are typically moved to the top of the reserve area. There are two exceptions to this. The first is if the reserve area and forward area is empty, and the pallet is moved straight to the forward area. The second exception is if the expiration date of the newly received pallets is closer in time than the pallets already in the reserve area.

The automatic cranes in the warehouse are used for handling of high frequency SKUs. These SKUs are put-away in the double-deep lanes, which are exclusively handled by the automatic cranes. The cranes can move more pallets in an hour than the workers can in a work day.

The put-away process is organized with respect to the product groups. Each product group is given a day of the week for restocking, with the exception of products only ordered when needed. SKUs of each product group are ordered from suppliers to be delivered on the day that they are to be put-away. This makes for an efficient put-away process.

When refilling the forward area, the workers do not necessarily wait until the storage location is completely empty. If there are only a few cartons left in the storage location, they may refill the location with a new pallet, and then place the remaining cartons on top of the new pallet.

Order-picking

While product is received in pallets, the order-picking is carton-pick-from-pallet. Cartons are picked from the whole pallet, and are stacked with cartons of other items, making a new mixed pallet which goes to the customer. The cartons that are to be placed on the mixed pallet is decided by the order list, generated from the WMS. The order route is also generated from the WMS. On the order list, the quantity given for each order line is the customer's desired number of cartons.

The order-picking method for manual handling at the warehouse can be categorized as discrete picking, as single picker picks all items for a single order. Benefits of this is that there is no need for sortation and consultation, and the entire order can be packed while picked. It can, however, lead to congestion in the aisles when many orders are picked simultaneously, and travel time can be excessive if there are few picks per order. The latter is not an issue at the warehouse, as the WMS generates order lists, aiming to pick full pallets to complete orders. The warehouse also practices zone picking to some extent, as the warehouse is divided into the three zones dry, chilled, and frozen, as well as the racks dedicated to automatic picking. The pickers do not move between the zones when picking orders. This method allows for different techniques and equipment for each zone, and can reduce travel time. A disadvantage to zoning is that it can be difficult to balance the workload in each zone. The warehouse handles this by moving employees from one zone to another if needed.

The warehouse practices pick-to-voice and bar-code scanning. The two methods are both well known methods for order-picking. Pick-to-voice is requires one headset and one microphone for each picker. For every pick, they are told the location and quantity of the next SKU that is to be picked from the order list. When they locate the SKU, they say the control number for the SKU they located, awaiting confirmation. For bar-code scanning, each picker needs a screen and a bar-code scanner. The screen shows the SKU and location of the SKU next to be picked from the order list. The bar-code scanner is used to scan the located SKU for confirmation. Both methods provide real-time pick confirmation and shortage indication, and are low cost. Neither method allows for the picker to make adjustments to the sequence of the order list. The next SKUs on the order list are unknown, as the picker is only presented with the next pick after the previous SKU is picked. While this is stated to be a disadvantage in the literature, the warehouse does not wish for the pickers to interfere with the order-route, as the route is generated by the WMS, and is calculated to be the most efficient route.

Throughout the picking route, the picker attempts to stack the pallet as well as possible. In some cases, the picker needs to rearrange, or set aside cartons on the truck before stacking them on the pallet to ensure that the pallet is stable and meet the correct dimensions. The warehouse keeps several different trucks available for order-picking. Long trucks have room for two pallets, sprinter trucks have room for three pallets, some trucks have a higher reach, and some trucks have a shelving system to set aside cartons while stacking the pallet as well as possible during the order route. The trucks can be used for different purposes. For example, trucks with higher reach are used to pick pallets from the higher up in the racks. The specialized trucks demand higher picking skills from the picker to operate efficiently. The order-picking process from the double-deep racks are performed automatically with the use of the automatic cranes.

Finished pallets from order picking in the chilled and frozen goods areas are directly transported from the cold areas to the trucks for delivery. This is due to the temperature requirements for these products.

Shipping

The warehouse distributes approximately 50 000 to 80 000 cartons every day. Dry goods are distributed throughout the week, with peak distribution on Mondays and Tuesdays. Fresh goods are also distributed every day of the week, with a peak of frozen goods on Mondays and Thursdays. Before distribution, finished pallets are checked for correct dimensions. The pallets ready for delivery are placed in an area on the floor near the out port. This area consists of several storage locations, one for each finished pallet. Each finished pallet is marked with a label including information about the contents, date, when it is to be delivered, and delivery route. If the delivery code starts with the number one, it implies that the pallet is to be delivered on a Monday.

6.2.3 Planning and control

Customer demand

The warehouse plans their inventory based on customer orders. The customers are retail stores. The retail stores start by sending an estimate of which goods they need at what time, called an advance order. Hereafter, they are restricted to a deadline for which they must send final orders. The retailers typically want to push this deadline as close to the delivery date as possible, as it provides them with a better understanding of the exact quantity they need. The warehouse, on the other hand, wants the deadline to be as early as possible, so that they can plan their inventory accordingly.

The warehouse utilizes master plans for overviews of orders. The plan is organized starting with the date and time for deliveries in store. It is also noted which type of products should be delivered at which days of the week, such as whether the retailer has ordered frozen goods or medicine. The warehouse then determines when the orders need to be finished, packed, checked, and ready for transportation. From here on, they determine when the deadline for final orders from the retailers must be to ensure that the warehouse can deliver the orders on time.

Fresh goods are not ordered from suppliers until an order from the customer is finalized. This is because of the perishability of the product. The warehouse does therefore not receive the fresh goods until immediately before it is delivered to the retailers.

In order to understand demand, the warehouse utilizes a purchasing system. This system gathers data from the WMS. The data includes registered orders, advance orders, and inventory status. The system calculates forecasts for what is expected to be sold for a given time period. This system accounts for estimated sales and the inventory at hand. When considering how future campaigns will affect the demand, the purchasing team communicates with the retailers. Together, they aim to identify what the demand for a given period of time will be for the SKU involved in the campaign.

The time period that the team considers when calculating demand varies from SKU to SKU. For products that have a stable demand throughout the year, the team considers the time period to be yearly. For products that are highly affected by seasonality and holidays, the time period is the length of the season or holiday. This applies especially to products that are only sold during for example Easter or Christmas, as they are not in inventory any other times during the year.

Staffing

The warehouse operates continuously from 21:00 on Sundays to 16:00 on Fridays. In this time period, there is a need for employees at the warehouse at all times. Shifts last 7.5 hours. The number of employees working simultaneously at the warehouse varies from day to day. This is planned with respect to the predicted material flow (volume) every day of the week. The aim is to balance the number of employees at work and the amount of work that needs to be done, reducing idle time. If there are more employees at the warehouse than there is work, the employees are set to do tasks such as cleaning, restocking the racks, moving SKUs, etc. The productivity of each employee is tracked through the WMS. This is followed up through productivity meetings. Employees are typically assigned to one of the three zones, dry, chilled, or frozen, for each shift. If there is a workload imbalance, this can be adjusted throughout the day.

6.2.4 Storage location assignment

The warehouse carries over 6000 different SKUs. All of these require their own unique storage location in the forward area, as well as storage locations in the reserve area. The warehouse practices a dedicated storage policy. This means that every SKU in inventory is assigned to a location in the warehouse, and no other SKU can be placed at that location. A dedicated storage policy minimizes handling costs, which is the warehouse's aim, and maximises building costs.

At the warehouse, the WMS keeps of control of inventory. This is where all information on storage locations is stored. The WMS finds the best location for all SKUs in the reserve area. The forward area, on the other hand, is manually organized. The decision-makers use historical data, sales data, the SKUs' properties such as weight, and knowledge of how seasonality affects demand to find the best storage location assignment for each SKU. Weather forecasts for the close future is also considered for products where weather affects the consumer demand. The retail stores' storage locations are highly contributing factors in this decision-making. In addition to this information, they use their experience to identify the best storage locations for the forward area. The aim of the storage location assignment is to reduce travel distance for the trucks during order-picking at the warehouse, as well as making it easier for the retailers to process the goods for restocking. The optimal storage locations at the warehouse is compared to that of the retailers. This means that if the warehouse calculates storage locations that reduces their travel distances, but increases the travel distances required at the retail stores, the warehouse does not make the change.

As previously mentioned, the warehouse has three zones for different temperatures: dry, fresh, and frozen goods. The dry zone keeps approximately half of the products in the warehouse. As products in the cool and frozen zone are more perishable than the products in the dry zone, they keep less pallets in the reserve area, to avoid waste due to expiration of products. In addition to the zoning of products into the three zones with different temperatures, the warehouse is organized into different product groups. This is linked with the retail stores. The warehouse is organized as close to the retailers' product locations as possible. This makes the put-away process for the retailers easier. Examples of product group zones are products located by the cash register, such as chewing gum and pastilles, spices, canned goods, goods for baking, etc. The product groups are located in a natural picking order.

Heavy items are placed in a way such that each picking route starts with the heavy goods. This improves the pallet's stability and reduces risk of damage to products. For this reason, the dry goods area is separated into two zones, both zones starting with heavy items. When a picker is finished in one of the zones, there is a hard break. This means that the picker finishes the pallet they were working on, even if it is not full, before starting a new pallet in the other zone. The separation of the two areas makes it easier to ensure that heavy goods are placed first on a pallet. There will never be products from both zones on one pallet.

The assortment of SKUs in the warehouse varies from time to time. As a rule, new products are introduced twice a year. At the same time as new products are introduced, old products are phased out. This calls for a reassessment of storage locations. New products may replace the old similar products, resulting in little change to the storage locations to be necessary. The new products will simply just take the storage location of the old product that is to be phased out. Other times, new products disrupt the storage locations to a point where there is no longer room for all the products of a product group in the same zone. When this happens, the warehouse needs to reconsider all storage locations, to identify where they can shift the products to make sure all the SKUs of one product group are located in the same zone. To support this decision-making, the team uses lists of all products that are added to the assortment, as well as lists of which products are going out of production. Through these lists, they can prepare the storage area for any switches in pickup locations that may be necessary.

For certain holidays, such as Easter and Christmas, the warehouse receives a new assortment of SKUs, limited to a short time period. The warehouse reserves a zone dedicated to these products. When there is a campaign on certain SKUs, the warehouse experiences a large increase in demand for the given SKU. To prepare for the increase in order frequency of the SKU, the warehouse can dedicate an area close to the out port to store the SKU on the floor. This solution reduces the travel distance for the trucks when picking pallets of this SKU. In general when considering each SKU's frequency, the team in charge of storage location assignment considers how many cartons of each SKU is sold. There is no defined parameter for which a SKU is considered to be classified as a high frequency product. These high frequency SKUs are located in favorable storage locations, making the picking process more efficient by reducing travel time for the SKUs.

The storage locations are not evaluated based on any KPIs. They are, however, evaluated by the order pickers. After an employee has finished picking an order, they can give feedback on the order-picking route, noting whether there are any SKUs that are not placed in logical storage locations. The knowledge of the decision-makers involved in storage location assignments in the forward area is not documented. They only document where SKUs are located, and changes made to the storage locations.

6.2.5 Decision-making related to storage location assignment

In the trade-off between handling costs and building costs, the case company chooses handling costs. This decision affects all decision levels of the storage location assignment. Firstly, there are the strategic decisions, which decisions already made for the long term organization of the storage area, and are set to support the overall aim of the warehouse. These are summarized in table 6.1.

Table 6.1: Strategic decisions affecting the storage location assignment at the warehouse

Decision area	**Description**
Warehouse layout design	The warehouse is separated into three zones: dry, chilled, and frozen. The forward area is located in the two first level of the pallet racks, and the reserve area is located from the third level of the racks.
Storage system design	The warehouse utilizes pallet racks for the storing inventory, both for the reserve area and the forward area. They utilize both manual labor and automatic cranes for the put-away and order-picking processes.
Storage policy	The warehouse practices a dedicated storage policy.
Static vs. dynamic	The SKUs are dedicated to permanent storage locations, implying a static storage location assignment. There is one exception to this, as products with sudden and temporary peak demand can be placed in temporary locations.

The second level of decisions at the warehouse are the tactical decisions. These build on the strategic decisions, and are focused on medium term considerations. The tactical decisions are summarized in table 6.2.

Table 6.2: Tactical decisions affecting the storage location assignment at the warehouse

Decision area	**Description**
Classification	The SKUs at the warehouse are classified in two: high frequency goods and the rest. High frequency goods are allocated favorable locations.
Zones	The warehouse has three zones that are decided by temperature requirements: dry, chilled, and frozen. Within the dry zone, there are certain racks that utilize automation, and the rest are handled manually. The dry area is also separated in two, demanding a hard break when order-pickers move from area 1 to area 2.
Product groups	SKUs are grouped based on the product family. The product groups are identified based on the retailer's storage locations. Goods limited to seasons, holidays, or special occasions are located in a a separate area.
Location of heavy items	Decision-makers locate heavy SKUs where the order route typically starts.
In-coming goods	The decision-makers evaluate whether they need to reallocate SKUs to different storage locations when there is a change in the warehouse's assortment, which happens twice a year.
Temporary storage locations	Referring to the strategic decision of dynamic vs. static storage locations, the warehouse opts to locate SKUs with sudden and brief peaks in demand at temporary storage locations near the I/O area.

Building on these strategic and tactical decisions, decision-makers regularly make short term decisions on where each SKU should be located in the forward area. These decisions are operational, and are made to reach the strategic goals of the company. They require information about the inventory's current status and information about the near future, such as demand characteristics and product characteristics of SKUs in inventory. This is listed in table 6.3.

Table 6.3: Operational decisions and information associated with storage location assignment at the warehouse

Decision area	**Information required**
Classification	Demand characteristics Customer orders Campaigns Seasonality and holidays
Zones	SKU-specific attributess
Product groups	SKU-specific attributes Seasonality and holidays
Location of heavy items	SKU-specific attributes
Temporary storage locations	Demand characteristics Campaigns
In-coming goods	Lists of in-coming and out-going goods Demand estimation

While the operational decisions visit the same decision areas as the tactical decisions, they are approached differently by the decision-makers. The operational decisions are made to implement the tactical and strategic decisions, are on an item specific level, and are short term. Unlike the strategic and tactical decisions, the operational decisions are made daily.

For classification of SKUs, the decision-makers separate the assortment in two classes: high frequency and low frequency. When deciding whether a SKU is of high frequency or not, they consider demand characteristics, customer orders, campaigns, and information about seasonality and holidays. This needs to be reviewed when there are new SKUs entering the warehouse, as well as whenever there is a change in demand. To assess the demand, data is gathered from the WMS. The warehouse used a purchasing system to calculate forecasts from this data. Campaigns are identified through direct communication with the retailers. The high frequency SKUs are located in favorable locations. In cases where a good is subject to a campaign, the SKU may be assigned to a different storage location in the I/O area, for a limited time.

The warehouse separates the storage area into three main zones. The zones are based on the temperature requirements for the different SKUs. There is one zone for dry goods, one for chilled goods, and one for frozen goods. When assigning the SKUs to storage locations, the decision-makers consider the physical product characteristics of each SKU. This information is found in the WMS under *goods in inventory*. Each SKU is thereafter assigned a storage location within the zone that fits the temperature criteria of the SKU. For products in inventory, this is a one time decision, as SKUs do not change their temperature requirements. For in-coming goods, the temperature requirements of each SKU needs to be identified before assigning the SKU to a storage location.

Within the temperature zones at the warehouse, the SKUs are sorted into product groups.

Which product group the SKU belongs to is decided through the physical characteristics of the product and the knowledge of whether it is a seasonal good or limited to a holiday or other special occasions. For SKUs already in inventory, new deliveries of the same good are brought to the SKU's assigned storage location. For in-coming goods, however, the decision of which product group the SKUs belong to needs to be made before deciding which storage location to assign it to.

When deciding where to locate heavy items, the decision-makers consider where the order route typically starts. They aim to locate the heavy items where the order-picker starts their order routes, so that they can easily be placed at the bottom of the pallets. Information about the physical characteristics of each SKU can be found in the *goods in inventory* functionality in the WMS.

The SKUs at the warehouse are dedicated to permanent storage locations, implying static storage location assignment. In cases of campaigns that lead to a high peak in demand for a period of time, however, they can sort to a temporary storage location for the SKU in question. This argues that the warehouse does practice a dynamic storage location assignment to some extent. It is, however, not very prominent. The decision of assigning a SKU to a temporary storage location is based on demand characteristics, analyzing if it is a sudden and brief peak in demand, and whether there is a campaign on the SKU. This needs to be continuously assessed.

Relocation of storage location assignments is mainly considered is when there is a change in the assortment at the warehouse. This happens twice a year. Information about in-coming and out-going goods can be found in the *substitution goods* functionality in the WMS. This functionality presents the in-coming and out-going goods, as well as the which location the out-going goods are stored in. Ideally, the warehouse will substitute the in-coming goods with the out-going goods, without any changes to the storage locations in the forward area. If there are more in-coming goods than storage locations released from out-going goods, they need to consider how to make alterations to the entire forward area, ensuring that SKUs of the same product groups are located near each other. Additionally, the decision-makers need to estimate the demand for the in-coming goods. When doing so, they typically consider historic demand for similar SKUs. This gives them an indication of whether the SKU requires a favorable location due to high frequency demand.

6.2.6 Solwr's WMS

The focus of this section is on features directed towards storage location assignment, and related processes.

Through the warehouse administration feature in Trace, the user receives an overview of the warehouse, with the option of making changes and maintenance at the warehouse. Within this feature, there are several functionalities for controlling the inventory: goods in inventory, block, move, generate restock, print labels, adjust in-coming goods, return to supplier, assign location, expiring goods, locations, and dedicated locations.

Goods in inventory: The first function is *goods in inventory*. This functionality shows all products in stock, and where they are located. The user has the possibility to search for products using several different criteria, such as location, SKU number, location type, pick type, amount in stock, supplier, serial shipping container code (SSCC), reserved amount, expiration date, batch number, available locations, blocked goods, etc. The user can then select a product to show information and make changes to the product. For example, one can correct the amount for a location or change the expiration date.

Block: Through the *block* function, one can select a SKU and block products within that SKU. One can either block the whole stock of a product, block a batch, or block a SSCC.

Move: The *move* function provides the option of moving a pallet from one location to another. This automatically generates an order for a truck to move the pallet.

Generate restock: Within the function *generate restock*, one choose to restock a location with more of the same SKU that is already located there. This also generates an order for a truck to move the selected amount of the pallet.

Print label: The *print label* function is used for printing a copy of the label for a selected pallet, which can be used if the original label is destroyed or lost.

Adjust in-coming goods: Through *adjust in-coming goods*, the user can send pallets directly to a location where there is already a different batch number.

Return to supplier: The *return to supplier* function provides the opportunity to adjust the amount that is to be returned to the supplier.

Assign location: The *assign location* function presents an overview of all products that are yet to be assigned to a location in the forward area and are expected to be received at the warehouse. When assigning a location to the SKU, the function presents information about the SKU, such as dimensions, weight, shelf life, etc., and suggestions to where it can be placed. Possible locations are based on where similar SKUs are located, such as products within the same product group. The function also presents a table of SKUs that are located near the proposed location for the selected SKU, and the closest location to a similar SKU.

Expiring goods: Within the *expiring goods* function, the user can see a list of all products that have expired, but are still located in the storage area. This provides an overview of which locations can be released and used for other products.

Location: The *location* function is how the user can build the storage area, by adding, changing, or removing locations. The function contains all the locations of the warehouse, from pickup locations to locations in the receiving area. Information in this function includes location type, location name, dedicated, amount of pallets the location stores, height, weight, and control number. This function, like the *goods in inventory*, also offers the option to search for location given several criteria, such as location type, pick type, dedicated location, dimensions, etc. When selecting a location, the user can show information about the location, and make changes to the name, type, height, maximum weight, capacity, dedicated to, control number, and restocking limit. One also has the option to block the location, preventing storing of new pallets. The function also offers the option of creating new locations, deleting locations, and printing labels for the location.

Dedicated location: Lastly, the *dedicated location* function shows all dedicated zones at the warehouse and a list of the items that are allowed in the dedicated zone. The function provides the opportunity to limit a location to a selected SKU or pick type.

In addition to this feature's functionalities, the warehouse administration also offers several reports: degree of utilization, substitution goods, production log, stock count, unfavorable locations, SSCC in a location, and locations lacking products.

Degree of utilization: *Degree of utilization* presents an overview of the occupied locations in a selected zone of the warehouse. It also shows a detailed overview of number of locations, number of occupied locations, number of free locations, what the degree of utilization is at all times, and degree of utilization for the dedicated locations.

Substitution goods: *Substitution goods* presents an overview of new in-coming SKUs that are to replace existing SKUs. In addition to this, it presents the location and the on hand inventory of the SKU, giving the user an overview of which locations should be released to a new SKU.

Production log: The *production log* presents an overview of finished tasks such as receiving goods, put-away, and order-picking. The overview can be presented as a total of the warehouse, or per user.

Stock count: *Stock count* generates the task of counting the inventory. This can be done regards to different criteria, such as counting the inventory in the forward area or the reserve area, whether it is to be counted on paper or using a screen. When the inventory has been counted, it needs to be controlled for approval. Any deviations are then noted and corrected in the system.

Unfavorable locations: *Unfavorable locations* provides the user with the opportunity to define criteria for certain SKUs. An example is if SKUs from one supplier should be located in one area. The function will then present an overview of SKUs that are located in unfavorable location with regards to the criteria.

SSCC in a location: *SSCC in a location* shows how many SSCC and which type are registered at the warehouse for a given location area, and whether they are stored in the forward area or the reserve area.

Location lacking products: Lastly, *locations lacking products* presents an overview of locations where the order pickers have reported a lack of products.

The Trace system also offers substantial tracking of all changes made to a product. The changes made to a product are when a product is moved from one location to another, order-picking, adjustments to inventory, inventory counts, receiving, etc.

Tracking: In the *tracking* functionality, one can make advanced searches using different criteria to specifically track what the user is looking for. The criteria one can search for are: SKU number, batch, location, user ID, SSCC, customer, order number, and customer order number. In addition to the search criteria, one can filter the search based on time interval, zones, type of task, etc.

Other functionalities worth mentioning are related to the receiving of goods, order-picking and map.

Receiving: The *receiving* function introduces the use of electronic data interchange. This enables the scanning of pallets and marking the pallets as received in the WMS. The amount, expiration date and batch number is then registered in the system. This can also be done manually.

Order-picking: The *order-picking* function enables bar-code scanning and pick-to-voice. The system generates the order-picking routes for the order pickers. Through bar-code scanning, the picker is able to note any shortcomings, if there is not enough cartons of the SKU that is to be picked at the storage location.

Map: The *map* function shows a graphical illustration of the warehouse and its locations. The function provides the option of searching for an order-picking route, and presenting the user with a visual representation of the route and how far the truck needs to drive to finish the route.

6.2.7 The warehouse's use of the WMS

The WMS stores all data about the storage locations of SKUs, product properties, orders, etc. At the warehouse, the WMS is mainly to supply other systems with data, tracking, generating order lists and order-picking routes, and assigning SKUs to the reserve area. The data available from the WMS forms the basis for other systems that the warehouse utilize. Regarding order-picking, the WMS generates order lists and order routes for the order-pickers. During the order routes, the order-pickers note any shortages, which are automatically updated in the WMS. When assigning product to the reserve area, the WMS searches for locations higher in the racks that are close to the SKU's location in the forward area. All the uses of the WMS provides the warehouse with control and tracking of inventory and all activities that occur at the warehouse.

For storage location assignment, the process is divided in two: storage location of the SKUs in the reserve area, and storage location assignment for the SKUs in the forward area. For the location assignment of SKUs in the reserve area, the WMS decides where to locate the stock of a SKU based on where there is room, and where the SKU is located in the forward area. The objective of the WMS is to locate the stock of the SKU in close proximity to its location in the forward area. Ideally, this is directly above the SKU. This is not possible for every SKU in practice, as there are too many SKUs compared to the storage space. The decision of where to locate pallets of SKUs in the forward area is made every time a new pallet enters the warehouse.

For the forward area, there is a team that locate each SKU with the objective of reducing travel distances for the order pickers. There are a few constraints identified for this decision of storage locations: the retail stores' storage location, the weight of the SKUs, temperature requirements, and product groups. Additional information needed for deciding the storage locations are lists of in-coming and out-going goods, storage locations of SKUs in the storage area, demand characteristics, the frequency of which the SKUs are ordered, campaigns, and to which degree the SKUs are affected by seasonality. Data on each SKU's weight, orders, temperature requirements, storage locations of all SKUs in inventory, and lists of in-coming and out-going goods can all be found in the WMS.

In order to understand the demand, and thereby understanding the frequency of which a SKU is ordered, the team utilizes a purchasing system. The system gathers data from the WMS, and transfers it directly to the purchasing system. This system provides information on advance orders, final orders, and forecasts. The results of this is used for the storage location assignment, discussed in the following section.

6.3 Challenges and improvement areas

The decision-makers at the warehouse rarely update the storage locations in the forward area. By updating the storage locations according to the current demand, at any time, one can reduce the time it take order-pickers to travel in order to complete orders for popular SKUs. As the aim of the design of the storage area is to minimize travel time, and hereby handling cost, this indicates that transitioning to a more dynamic storage strategy can help the warehouse in reaching this goal. An assumption for why they do not update the storage locations frequently, is that it is a time-consuming and difficult process of analyzing which storage locations are optimal for which SKU. To make this process easier, one should improve the decision-support for the decision-makers, highlighting and visualizing the information they need. This section identifies challenges and improvement areas at the warehouse regarding storage location assignment.

There is a lot of literature in how the SLAP is solved using mathematical modelling. At the warehouse, there is a team of decision-makers, using their experience, information about future demand, and information about the SKUs in storage to decide which storage location the SKUs should be assigned to. As the warehouse does not utilize mathematical models, but rather a team of decision-makers, there is a need for decision support to aid them in the storage location assignment.

One of the challenges of warehouses in the FMCG industry is the varying demand and the quick turnover. The products' perishability adds a level of complexity to inventory control.

This demands for the warehouses in the industry to predict the customer demand, which is highly dependent on information flow from the retailers. For such dynamic material flows, the literature points to the benefits of implementing a dynamic storage policy.

The most prominent constraint for storage location assignment at the warehouse considers the SKUs' product groups. The storage area needs to be organized with respect to the retailers' product groups. Information about the SKUs' product groups must therefore be considered in any other decision made in regards to the storage location assignment. This makes for a complex storage location assignment in regards to the other decision areas that needs to be considered when identifying the optimal storage locations for each SKU. An area of improvement is to implement the product groups in every decision area of storage location assignment, making this information easily accessible and visible.

Another challenge of warehouses in the FMCG industry is the changes in assortment. From time to time, products are removed from stores, at the same time as new products are introduced. Based on what has been identified from the warehouse, this is one of the critical times for considering changing storage locations. When considering storage locations of new in-coming SKUs, the team of decision-makers compare lists of in-coming and out-going SKUs. They then need to decide whether to make changes to all the SKUs storage locations to make sure that the new SKUs can be located with their product group, or if the new SKUs can simply be assigned to the out-going SKUs' storage locations.

Based on the current situation, another critical time for considering deciding the storage location assignment, is when there is an increase in frequency for a SKU. The decision-makers classify SKUs based on demand frequency: high frequency or low frequency. They do not have a set definition of what is considered a high frequency SKU. Setting a requirement for the number of cartons sold over a specific time period to classify the SKU as a high frequency good could make the process of classification easier.

To summarize, the warehouse is subject to large demand variations, the complexity of perishable goods and many product groups, and a large assortment of different SKUs. The aim of the decision-makers is to locate SKUs in a way that minimizes travel time for the order-pickers, while considering the product groups to minimize the put-away time for the retailers. The complexity of the storage location assignment calls for the decision-makers to have all the necessary information available to ensure that this process runs smoothly. Making the process of identifying optimal storage locations for the SKUs can enable the decision-makers to update the storage locations more frequently. This can enable a more dynamic storage location assignment, and adjust the locations to the varying demand.

6.4 Suggestions

This section presents suggestions for the case based on the identified challenges and improvement areas. The suggestions are separated into suggestions for storage location assignment regarding the decision-making process, the information needed for this decision-making, and how the information can be presented. The suggestions focus on the operational decisions identified in table 6.3. The reason for this is that these are the decisions where the decision-makers assign storage locations to fulfill the strategic decisions. The information needed for these decisions is mainly gathered from these functions in Trace: goods in inventory, substitution goods, and unfavorable locations. These are the functions that provide extensive information about the SKUs in inventory, in-coming and out-going goods, and identified SKUs located in unfavorable locations. Other useful functions that provide overviews of either locations or the total storage area are assign location, location, dedicated location, and map.

6.4.1 Suggestions for decision-making

The two suggestions for decision-making at the warehouse are as follows:

1. Evaluate storage locations more frequently.
2. Set a criteria for classification of high frequency SKUs.

The first suggestion for the decision-making process at the warehouse is to evaluate the storage locations more frequently. This is a step towards a dynamic approach to the storage location assignment, will help ensure that the storage locations are suited for the demand at the time. To realize this, the decision-makers need the necessary information for reallocating SKUs to new storage locations, and for the information to be easily understood.

The second suggestion is related to classification of SKUs. To make it easier for the decision-makers to classify SKUs, they should set a criteria for the lowest demand frequency a SKU can have to be classified as a high frequency good. This will eliminate the SKUs that have the lowest demand frequency, giving the decision-makers a narrower selection of SKUs to decide from.

6.4.2 Suggestions for information needed for decision support

This section presents four suggestions for information that can simplify the decision-making process of assigning SKUs to storage locations. The suggestions are listed as follows:

1. Include product groups of in-coming and out-going goods.
2. Note which product group all SKUs belong to.
3. Gather feedback from order-pickers on unfavorable storage locations.
4. Comparison of historic demand to predicted demand for classification of SKUs.

To simplify the process of assigning in-coming goods to storage locations, it would benefit the decision-makers to have easily accessible information about both in-coming goods and out-going goods. One suggestion for this is to include which product groups both the in-coming and out-going goods belong to. This will show the decision-makers how many storage locations of each product group will be released, and how many storage locations are needed within each product group.

The second suggestion is to note which product group each SKU belongs to. As product groups affect where all SKUs should be located in the storage area, this is valuable information to consider in all aspects of decision-making regarding storage location assignment. Making this information accessible and from every relevant function in the WMS could simplify the process of assigning storage locations.

The third suggestion regards identifying unfavorable locations. As previously identified, the warehouse gathers feedback from order-pickers on SKU's storage locations in the forward area. The order-pickers can note if they consider a SKU to be located in an unfavorable location. This feedback should be gathered and sorted with respect to the SKUs, noting how many times a SKU's location has been deemed unfavorable. This can help the decision-makers identify when there is a need for changes in the storage locations.

The forth and last suggestion regarding information for storage location assignment involves identifying demand changes. To improve the method for classifying high frequency SKUs, the decision-makers should compare the SKUs historic demand to the predicted demand. The suggestion is to utilize their forecasting methods based on historic demand to a predictive approach including factors such as weather forecasts and information about demand from retailers. This can help identify when SKUs that are normally classified as a low frequency SKU have a sudden and brief peak in demand.

6.4.3 Suggestions for presentation of information

This section introduces four suggestions to changes to existing functionalities in Trace, as well as a suggestion for a new functionality in the system. Table 6.4 lists the suggestions for functionalities of the WMS for the case study, introducing the key points for each suggestion. *Improvement* indicates that the suggestion builds on an existing functionality of the WMS. *New functionality* indicates that the suggestion involves making a new functionality.

Table 6.4: Suggestions for functionalities to support decision-making related to storage location assignment in Trace

Function	Description of suggestion
Substitution goods	*Improvement* 1. List out-going and in-coming goods by product group. 2. Mark how many SKUs of both in-coming and out-going goods are in each product group. 3. Mark out-going goods on map of storage area.
Goods in inventory	*Improvement* 1. Create *product groups* as a search criteria. 2. Indicate whether the SKU is limited to a holiday or special occasion. 3. Implement the SKUs' class, with the option of using it as a search criteria and change the SKUs' class.
Unfavorable location	*Improvement* 1. Implement the feedback on storage locations from order-pickers in the functionality. 2. Visualize the locations deemed as unfavorable on a map of the storage area. 3. Indicate whether the location is deemed unfavorable seen from the order-pickers' perspective and/or from the defined criteria. 4. Option to view how many times the storage location has been said to be unfavorable.
Demand analysis	*New functionality* 1. Gathers data from retailers on expected demand for a given time period. 2. Calculates forecast from the same time period, based on historic demand. 3. Suggests classification for all SKUs, in both scenarios, highlights the SKUs with two different classes.

Substitution goods function:

The first suggestion is an improvement to the *substitution goods* function in Trace. As stated by the warehouse, they mainly look into relocation of SKUs to new storage locations in the forward the two times a year where there is a change in the assortment. When assigning the new SKUs to storage locations, the decision-makers firstly check if the new SKUs can simply be assigned to the storage locations of out-going goods. In an aim to make this easier for the decision-makers to consider, the first improvement is to list the out-going and in-coming goods by the product group they belong to. This provides the decision-makers with a descriptive overview of all the changes in the assortment. The second improvement is to note the number of out-going and in-coming goods for each product group. This clarifies if there is an increase or decrease in the assortment for each product group. Furthermore, this makes it easier for the decision-makers to decide whether they need to make substantial changes to the storage locations, or if they can simply allocate the in-coming goods to the out-going goods' storage locations. The third improvement is to utilize the map of the storage area from the *map* function to visualize where the out-going goods are located, marking their storage location. This visualization can further improve the decision-makers' understanding of where the storage locations that will be freed from the out-going goods are located.

Goods in inventory function:

The second suggestion involves improvements to the *goods in inventory* function. As previously mentioned, it has been made evident that product groups are highly important when the decision-makers decide where to assign SKUs to storage locations. The first improvement to the function is therefore to create a new search criteria called *product groups*, as well as indicating which product group each SKU belongs to in the product description. This provides the user with the opportunity to view all SKUs' within a product group. Secondly, the warehouse keeps a section of racks dedicated to seasonal products, limited to a holiday or special occasions. The next suggestion is therefore to indicate that these SKUs are seasonal in the product description of the SKU, as well as making *seasonal goods* a search criteria in the function. The third improvement is to implement the SKUs' class in the product description of each SKU, and, again, create a new search criteria enabling the user to view all SKU of each class. When viewing a SKU within this function, the user should have the option to change the SKU's class as they see fit. This improvement will provide the decision-makers with a better understanding of how many SKUs and which SKUs are high frequency, and which are not. The aim of including this in the functionality is to make it easier for the decision-makers to make dynamic changes to an otherwise static approach to storage location assignments.

Unfavorable location function:

The third suggestion involves the *unfavorable location* function in Trace. While the function provides the user with the option of defining criteria for storage locations in order for the system to analyze whether there are any unfavorable locations, the warehouse use feedback from order-pickers to identify any unfavorable location. The first improvement is therefore to bring this feedback from the order-pickers into the function. To further improve the decision-makers' understanding of whether they should consider relocating SKUs, the second improvement involves utilizing the map of the storage area. The locations deemed as unfavorable should be marked on this map, creating a visualization of where there is a need to reconsider storage locations. Furthermore, each storage location marked as unfavorable should indicate whether the location is deemed unfavorable seen from the order-pickers' perspective and/or from the defined criteria in the system. The indication could be in form of color coding the storage locations. This could bring the opportunity of identifying any patterns between the two, and further support the decision of moving the SKUs from the unfavorable locations. Lastly, the function should provide an option to view a list of all the unfavorable locations, noting how many times the location has been said to be unfavorable by the order-pickers. This will provide the decision-makers with support for deciding which storage locations are urgent to change. The functionality can bring an understanding of whether the overall location assignments are satisfactory.

Demand analysis function:

The last suggestion is a new function for *demand analysis*. The idea for the functionality is to utilize both forecasts based on historic demand and forecasts based on information from the retailers. The warehouse has a static approach to storage locations assignment, with the exception of locating SKUs with a peak demand in a dedicated area near the I/O port when necessary. To support the decision-makers in these situations, it would be fruitful to present them with information about the demand and expected changes in the demand in relation to campaigns. The first step is to gather information from retailers on expected demand for a given time period. This should include the knowledge of any upcoming campaigns. The second step is to calculate the forecast from the same time period based on historic demand, accounting for seasonality. Each forecasting scenario should suggest classification of all SKUs for the given time period. To compare the demand for each SKU, the function should highlight any SKUs with different classes for the two scenarios. This functionality can, for example, present the user with an indication of which SKUs that normally have a low frequency are expected to have an increase in demand. This provides them with decision support for moving the SKU to a temporary storage location in the time period of peak demand.

6.5 Discussion

This section discusses the suggestions from section 6.4. The discussion is divided into three parts: decision-making, information for decision-making and presentation of information for decision-making. Following the discussion of each suggestion, further work for the companies of the case study is discussed.

6.5.1 Decision-making

The decision-makers rarely make changes to the storage locations. This may be because information is not easily accessible, making it hard to analyze whether there is a need to reassign storage locations. With the dynamic material flow at the warehouse, literature recommends a dynamic storage policy. The storage locations will then accommodate the demand at any given time, not just the average demand. This will further improve the warehouse's efforts in minimizing handling costs.

The warehouse classifies products based on frequency. SKUs of high frequency are given favorable storage locations. The literature points to ABC-classification of products. This classification implies a categorizing of products into three, from most important to least important. Importance can be measured in frequency, like the warehouse does. An ABC-classification will arguably increase the warehouse control, as one differentiates between more products, than just identifying which have the highest frequency. However, as storage locations are highly prioritized based on product groups, it can be sufficient with only the two classes the warehouse uses in practice.

6.5.2 Information for decision support

As gathered from the suggestions, information is the key factor in ensuring easier and less time-consuming storage location assignment for the decision-makers. This section discusses the information needed for different decision areas, building on the suggestions from section 6.4.

The first decision area that was visited is the information for in-coming and out-going goods, referring to the change in assortment that happens twice a year at the warehouse. This is the one concrete situation where the decision-makers need to assess whether or not to make changes to the SKUs' storage location assignment. Product groups have been identified to be very important for the storage location assignment. Systematically sorting the in-coming and out-going goods from the product group they belong to, can therefore make it easier for the decision-makers to identify any changes that needs to be made in the storage locations for each product group.

The second decision area that was visited was related to product groups in general. To further aid decision-makers in any decision related to storage location assignment, one should increase visibility of which product group each SKU belongs to. As the SKUs' product groups need to be considered in every decision area, this information needs to be readily accessible from the WMS.

The third situation visited was identifying unfavorable locations. As the warehouse does not change the storage location assignments frequently, it is fruitful for them to easily identify when there are SKUs located in unfavorable locations. As mentioned, the order-pickers give feedback on storage locations that they deem unfavorable. What is done with this feedback, however, is not clear. To utilize the feedback and transform it into information the decision-makers can easily analyze, gathering and sorting the feedback with respect to each SKU can be valuable. The number of times a SKU's storage location has been deemed unfavorable should also be noted. Making this information available to the decision-makers enables them to immediately identify SKUs that require a change in storage locations, without needing to perform extensive analyses.

The last decision area visited is related to changes in demand. FMCG are subject to large variations in demand, may be subject to sudden and brief cases of peak demand due to for example campaigns. To capture this, it could be useful to separate between demand forecasts based on historic demand, accounting for factors such as seasonality, and predictive forecasts based on factors such as campaigns communicated by retailers and weather forecasts. This could help identify classification based on regular demand, and classification for shorter time periods in the near future. A result from this is that decision-makers are presented with an overview of SKUs that may need temporary storage locations in times of peak demand. This can simplify the decision-making of which SKUs need permanent favorable locations, and which SKUs can benefit from a dynamic approach to storage locations.

6.5.3 Presentation of information for decision-making

This section discusses the suggestions for improvements to existing functions in Solwr's WMS, and the suggestion of implementing a new function in the system.

Substitution goods

As made clear throughout the case study, the two times where it is critical that the decision-makers need to assess whether or not to change SKUs' storage locations are when there is a change in the assortment at the warehouse. For this reason, this assessment can benefit from presenting important information in an understandable way. The suggestion focuses on defining which product group out-going and in-coming products belong to, and mark the out-going goods on a map of the storage area. The suggestion requires for every in-coming good to be sorted into a product group before they are assigned to a storage location. Additionally, Solwr needs to further investigate how the *map* function can be utilized in the *substitution goods* function, marking the outgoing SKUs on the map of the storage area.

Goods in inventory

Creating *product groups* and *holiday* or *special occasion* product as search criteria of the *goods in inventory* function can aid the decision-makers by providing them with an overview of the different groups of the SKUs in inventory. This is useful as different types of SKUs are typically located near similar SKUs, which greatly affects storage location assignment. Including classification of all SKUs in this function provides visability of this information. This requires the user to input classes for each SKU in the WMS. Increasing the number of product classes could be interesting to increase differentiation between SKUs. As they are highly dependent on keeping SKUs of the same product groups stored together, it may not lead to much improvement. To analyze the impact of increasing the number of classes, further studies are needed.

Unfavorable location

For the warehouse, which does not change storage locations frequently, it is critical to identify whenever a SKU is located in unfavorable locations. Considering both the order-pickers feedback and the WMS's option of defining criteria for which a SKU's storage location is considered sufficient, can provide the decision-maker with an understanding of whether SKUs are located in unfavorable locations or not. Presenting this through color coding of storage locations and indications of how many times a SKU's storage location has been deemed unfavorable could make need for changes evident for the decision-makers, not requiring extensive analyses. The improvement to the function in Trace demands for the feedback from order-pickers to be translated for the WMS. Furthermore, how the data can be used to provide for example color coding of storage locations needs to be investigated.

Demand analysis

The new proposed function combines forecasted demand based on historic demand, and forecasts with a predictive approach, taking into consideration knowledge of campaigns and weather forecasts. By classifying SKUs with respect to both approaches can help decision-makers identify which SKUs have a stable yearly demand and which are subject to demand fluctuations. This can aid them in identifying which SKUs can benefit from temporary favorable storage locations and when. A prerequisite for this function is that the system needs information about demand from the retailers. The decision-makers also need to define a range for which a SKU is to be considered of high frequency. The classification provided from this functionality can further be used to help decision-makers define classes for the SKUs, and potentially discover whether their assessment of classification must be adjusted.

Overall

Overall, the suggestions work to make valuable information easily accessible and visible from the functions used for storage location assignment. Integrating product groups in all functions can aid the decision-makers when making decisions on other decision area, while still considering the constraint that is the product groups. The suggestions do not aim to remove the decision-makers from the process of storage location assignment, but rather provide them with decision support to make the process easier and less time consuming. This can enable them to perform assessments of the storage locations more frequently, moving towards a more dynamic approach, accommodating the varying demand of FMCG.

6.5.4 Limitations and further work

The first and most critical limitation of the case study, is that there are no in depth interview with the decision-makers who work closely with storage location assignment. Therefore, there may be insufficient information on how the decision-makers assess and approach making changes to storage locations. As a result, the suggestions for decision-making and information for decision support may visit actions that are already in place at the warehouse.

The second limitation of the case study is that I have not experienced the WMS first hand, but only through descriptions of the functionalities. The case therefore discusses all the relevant data available from the system, and how the functionalities are presented to the user, but lack a deeper understanding of how one uses the system. The suggestions for presentation of information in the WMS may therefore not be possible to realize.

Next steps for the case company and Solwr

The first next step for the case company is to evaluate whether they see potential in the suggestions. Firstly, they must check if the analysis of the decision-making process is correct. Secondly, they must evaluate if the analysis of the information they need for decision support is relevant for their purposes. Furthermore, whether the information is readily available must be identified. Any discrepancies should be reported for possible improvements.

If the company should decide to implement any of the suggestions, they should evaluate whether the decision-making process improves. As the aim of the suggestions is to enable the decision-makers to easily understand when there is a need for change, and to make the process less time consuming, this should be the evaluation requirements.

For the company to implement the suggestions, actions from Solwr are necessary. Solwr needs to investigate which data they need to translate into information and which measures are necessary to implement the information in the functionalities. Before doing so, they need to evaluate whether the information can be made available for presentation.

7 Discussion

This chapter connects the findings from the literature study and the case study. The findings are discussed through the research questions of the study. This is separated into three sections, one for each research question.

7.1 Decision-making in storage location assignment

RQ1: *How are decisions regarding storage location assignment made today?*

The literature implies that solving the SLAP requires the use of mathematical models, due to the complexity of the problem. The models studied, however, require heuristic approaches, or the use of fuzzy logic, as they cannot solve the problem exactly. There will always be a need for people to overlook the models that are in place. This argues for the need for decision support for decision-makers, regardless of whether they utilize mathematical models or not. Therefore, it is fruitful to have a set of functionalities in the WMS for decision support in analyzing whether or not the proposed storage location assignment is optimal for the time being, and in the future.

The case study approaches storage location assignment differently for the reserve area and the forward area. The assigning of SKUs to storage locations in the reserve area is automated through the WMS, while for the forward area, the process is performed by decision-makers. The reviewed literature does not point to separation of these processes.

The practical perspective reveals that SKUs are rarely relocated in the forward area. As the warehouse has a dynamic material flow, this means that they do not reap the benefits of a dynamic storage location, decreasing travel time by updating the storage locations for the demand at any given time. This requires demand pattern analysis. If there are forecasts in place, one can discover when a product is expected to have an increase or decrease in demand, reevaluate the classification, and prepare the change in location hereafter. When there are changes to the number of SKUs or the amount of each SKU, the storage locations will be affected. It may also affect how one should classify the products. This argues that there is a need for continuous review of the storage locations and classifications of products, further supporting the need for a more dynamic approach to storage location assignment.

Through the case study, there were three identified situations where the decision-makers will consider to reassign SKUs to a different storage location in the forward area. Twice a year, the assortment of products at the warehouse is changed. Both in-coming and out-going stock-keeping-unit (SKU)s need to be accounted for. The decision-makers then evaluate whether the in-coming SKUs can simply replace the out-going SKUs, or if they need to make adjustments to all the storage locations in order to fit the new SKUs within their product group's zone. The operational decision of assigning in-coming SKUs to storage locations is overlooked by the literature. Through the case study, it was made clear that this is a critical time for storage location assignment.

Other times where the decision-makers evaluate new storage locations for SKUs are when there are campaigns for certain products, which is common for FMCG. Campaigns may change the SKU's classification from a lower frequency to a high frequency SKU. To accommodate the change in frequency, the decision-makers can dedicate an area close to the I/O port to the SKU for the period of time that the frequency is expected to be high. This helps decrease the travel time for order-pickers.

The last identified situation identified though the case study is the reassigning of products to new storage locations based on whether they are perceived as unfavorable. The warehouse considers this based on the order-pickers give feedback on the SKU's location in the forward area. After every order route, the order-pickers can note if there are any SKUs that are located in unfavorable locations. The WMS also offers a functionality for identifying unfavorable locations, but it is unknown whether this is actually used at the warehouse.

The following list presents the operational decisions that need to be made regarding the storage location assignment, combining the decision areas identified through the literature study and the case study.

1. Classifying each SKUs based on their demand frequency or other criteria to categorize their importance
2. Deciding which zone of the warehouse each SKU belongs to.
3. Identifying which product group each SKU belongs to.
4. Classify each SKU based on their weight for location of heavy items.
5. Identify when a SKU should be assigned a temporary storage location based on a brief and sudden peak in demand.
6. Assigning in-coming SKUs to storage locations.

The first four operational decisions are identified through both the literature study and the case study. The last two operational decisions, however, are identified through the case study. This implies that there are more operational decisions made in practice than what the literature suggests, arguing that storage location assignment for FMCG is more complex than the literature states.

7.2 Information needed for decision support in storage location assignment

RQ2: *Which information is needed for decision support in storage location assignment?*

Information about in-coming and out-going goods in the assortment is highly important for assigning the in-coming goods to storage locations. This enables the decision-makers to see which storage locations become available, and which SKUs require new storage locations. The information is used to decide whether the in-coming goods simply can take the out-going goods locations, or if there needs to be made changes to all storage location to ensure that SKUs of the same product groups are stored together. This topic is not discussed in the reviewed literature, which may be a result of the mathematical models indirectly considering this when assigning storage locations. The WMS studied in the case offers a functionality with lists of in-coming and out-going goods. To further improve the use of this functionality, the information should include information about the SKUs' product groups. This enables to decision-makers to identify which areas of the storage area are affected by the change in assortment.

As identified through the case study, the storage locations are highly dependent on each SKU's product group. The decision-makers require general information and product properties of all the SKUs in the warehouse. They need to know the dimensions of the SKUs, such as whether it is a heavy product, which type of product it is, to understand which product group it belongs to, and whether the SKUs are to be located in the dry, chilled, or frozen area. This information must be easily accessible, visible, and understandable from the functionalities of the WMS.

Through the case study, it was made known that to identify unfavorable locations, feedback from the order-pickers is gathered. The WMS also offers a functionality on this area. The user can define criteria for storage locations, and the functionality will identify unfavorable locations. This topic is not discussed in the reviewed literature. A reason for this may be the prominent use of mathematical models, which will automatically identify the optimal storage locations, and therefore reassign SKUs located in unfavorable locations to favorable locations.

To accommodate the varying demand of the FMCG industry, one needs to approach the storage location assignment dynamically. This requires the use of lead measurements, predicting what the demand will be for each SKU in the future to prepare for decreases and increases in demand. As made know through the case study, historic data is used to predict product demand, in addition to advance orders and final orders. The literature points to the importance of predicting customer demand for dynamic storage location assignment. To identify when a SKU's classification is based on a brief and sudden peak in demand, or rather a stable high demand frequency, both historic demand and predicted demand should be available for comparison. This can enable decision-makers at a warehouse to decide whether to assign SKUs to temporary favorable locations in the I/O are or permanent favorable locations in the pallet racks in the forward area.

The following list summarizes the information needed for operational decisions related to storage location assignment, based on the practical perspective, the system perspective, and the literature perspective.

1. Include information on product groups of in-coming and out-going goods.
2. Note which product group all SKUs belong to.
3. Gather feedback from order-pickers on unfavorable locations, as well as the unfavorable locations identified through the WMS.
4. Provide comparisons of historic demand and predicted demand of all SKUs, offering classification of the SKUs both based on historic demand and predicted demand.

7.3 Presenting information to decision-makers for handling of storage location assignment

RQ3: *How can information be presented for decision-makers to best aid them in decision-making regarding storage location assignment?*

In the FMCG industry, warehouses are subject to changes in assortment. As identified through the case study, it is important to assign SKUs to storage locations based on their product group's location. To simplify the process of assigning incoming goods to storage locations, information about product groups should therefore be presented to the decision-makers. Furthermore, this should be visualized on a map of the storage area, to make it easier for decision-makers to understand which locations in the storage area will be freed by out-going goods.

Information about product groups is needed in every aspect of storage location assignment. To make this accessible, each SKU's product group should be noted in the functionality presenting all goods in inventory. Furthermore, there should be an option to search for SKUs based on their product group.

Through the case study, it was made known that the warehouse does not update storage locations regularly. To make it easier for decision-makers to identify when there is a need for change in storage locations, there should be a functionality that presents unfavorable locations. This can both include defined criteria for what is a favorable location, and feedback from order-pickers.

Lastly, the FMCG's variable demand is a challenge for storage location assignment. As a result, the SKUs' classification can vary on a regular basis. To enable decision-makers to understand whether a SKU needs a permanent favorable location due to their classification, or rather a temporary favorable location due to a sudden and brief peak in demand, comparisons of historic and predicted demand should be presented. If the decision-makers are presented with one classification based on historic demand, and one based on predicted demand for the near future, they can easily identify when there is a change in the SKUs' demand.

Table 7.1 presents requirement specifications for functionalities in a WMS. The functionalities aim to provide decision support on the identified decision in need of extensive information.

Table 7.1: Requirement specifications for functionalities in a WMS for decision support

Functionality	Description
Changes in assortment	1. List out-going and in-coming goods by product group. 2. Mark how many SKUs of both in-coming and out-going goods are in each product group. 3. Mark out-going goods on map of storage area. 4. Mark product groups on map of storage area.
Goods in inventory	1. Create a search criteria called *product groups* in the functionality with an overview of goods in inventory. 2. Indicate whether the SKU is limited to a holiday or special occasion in the SKU-specific attributes for all SKUs. 3. Implement the SKUs' class, with the option of using it as a search criteria and change the SKUs' class.
Unfavorable location	1. Implement feedback on storage locations from order-pickers in the functionality. 2. Visualize the locations deemed as unfavorable on a map of the storage area. 3. Indicate whether the location is deemed unfavorable seen from the order-pickers' perspective and/or from the defined criteria. 4. Option to view how many times the storage location has been said to be unfavorable.
Demand analysis	1. Gathers data from retailers on expected demand for a given time period. 2. Calculates forecast from the same time period, based on historic demand. 3. Suggests classification for all SKUs, in both scenarios, highlights the SKUs with two different classes.

7.4 Limitations and further work

The main limitation of the study is that there is only one case study. This makes it difficult to generalize the results, as the observations they are based on may only be applicable to the one case. There is, however, reason to believe that the case is characteristic to that of any warehouse in the FMCG industry. Furthermore, the storage location assignment is studied for manual warehouses in the FMCG industry. To be applicable for other industries, other decisions and criteria may be favorable.

Another weakness of the study is that I did not speak directly to the decision-makers that specialize in storage location assignment at the warehouse. As a result, the information about the decision-making process may be lack depth.

For further work, multiple case studies should be conducted, with different warehouses and different WMSs. This will strengthen the findings from the study, and make it possible to generalize the results.

To implement the suggestions of the study, further work related to the data and tools necessary to realize the decision support must be identified. To attain the information for the functionalities, one needs to identify which data is necessary, and how it can be translated into information. The data translation must thereafter be performed.

8 Conclusion

The aim of this study was to investigate which information decision-makers need when approaching storage location assignment, and how this information can be presented in a WMS for decision support. This was investigated through a literature study and a case study of Solwr and a warehouse that utilizes their WMS Trace in the FMCG industry. The study posed three research questions. The questions involve how decisions regarding storage location assignment is made today, which information is needed for decision support, and how this information can be presented to aid decision-makers.

Strategic decisions lay the foundation and direction of the warehouse, guiding decision-makers in their operational decisions. The identified decision-areas are related to classification, zoning, product groups, location of heavy items, temporary storage locations, and in-coming goods. To assign SKUs to appropriate storage locations, the decision-makers need information about demand characteristics, customer order, campaigns, seasonality and holidays, physical product characteristics, and lists of in-coming and out-going goods. To aid the decision-makers, this information needs to be presented clearly. The suggestions to functionalities in the WMS include implementing product groups throughout the system's functionalities, making this information easily accessible and visible, gathering feedback from order-pickers on unfavorable locations and combining it with the unfavorable location function in the system, and comparing forecasts based on historic data to that of predictive forecasts including campaigns for classification.

The main contribution of the study is that storage location assignment is approached from the user's point of view, while the literature focuses on complex mathematical models. The results reflect what the decision-makers at a warehouse in the FMCG industry need to make qualified decision related to storage location assignment without the use of mathematical modelling. While the results do not provide the warehouse with a solution to the SLAP, it provides decision support which makes it easier and less time consuming to identify the need for changes in the SKUs storage locations.

The contributions to the WMS is a requirement specification for functionalities that can utilize information for decision support for storage location assignment, which was the objective of the study.

The main limitation of the study is that only one single case has been investigated. The results are therefore difficult to generalize, and may only be applicable for this particular case. There is, however, reason to believe that the identified decision areas and information needed for decision support is relevant for other retail distribution centers operating in the FMCG industry.

Before the results can be implemented, one needs to investigate which data is necessary to attain the information from the WMS. Furthermore, how the information can be presented through the data needs to be analyzed.

References

Aasheim, S., & Cherrie, E. E. F. (2022). *Dynamic Storage Location Assignment Using Operator Idle Time for Reshuffling of Goods in a Manually Operated Warehouse* (Master's thesis). NTNU.

Ahmed, M., van Blokland, W. W. B., & Maknoon, Y. (2021). Storage assignment in the steel manufacturing industry: Mathematical modeling and a priority-based heuristic approach. *Journal of Supply Chain Management Science*, *2*(1-2), 33–46.

Ajol, T. A., Gran, S. S., & Ali, A. N. A. (2018). Minimizing Warehouse Operation Cost. In *Proceedings of the second international conference on the future of asean (icofa) 2017–volume 2: Science and technology* (pp. 625–634).

Anderson, K., & McAdam, R. (2004). A critique of benchmarking and performance measurement: lead or lag? *Benchmarking: an international Journal*, *11*(5), 465–483.

Arnold, J. R. T., Chapman, S. N., & Clive, L. M. (2008). *Introduction to Materials Management* (6th ed.). Pearson.

Arunraj, N. S., Ahrens, D., & Fernandes, M. (2016). Application of SARIMAX model to forecast daily sales in food retail industry. *International Journal of Operations Research and Information Systems (IJORIS)*, *7*(2), 1–21.

Bala, M., & Kumar, D. (2011). Supply chain performance attributes for the fast moving consumer goods industry. *Journal of Transport and Supply Chain Management*, *5*(1), 23–38.

Bartholdi, J. J., & Hackman, S. T. (2019). *Warehouse and Distribution Science* (Master's thesis). Georgia Institute of Technology.

Baruffaldi, G., Accorsi, R., Manzini, R., & Ferrari, E. (2020). Warehousing process performance improvement: a tailored framework for 3PL. *Business Process Management Journal*, *26*(6), 1619–1641.

Bašljan, I., Munitić, N. F., Perić, N., & Lešić, V. (2021). Prediction of perishable goods deliveries by GRU neural networks for reduction of logistics costs. In *2021 ieee international conference on technology management, operations and decisions (ictmod)* (pp. 1–6).

Basson, L. M., Kilbourn, P. J., & Walters, J. (2019). Forecast accuracy in demand planning: A fast-moving consumer goods case study. *Journal of Transport and Supply Chain Management*, *13*(1), 1–9.

Bruel, O. (2016). *Strategic sourcing management: Structural and operational decision-making*. Kogan Page Publishers.

Brynzér, H., & Johansson, M. I. (1996). Storage location assignment: Using the product structure to reduce order picking times. *International Journal of Production Economics*, *46*, 595–603.

Cai, J., Liu, X., Xiao, Z., & Liu, J. (2009). Improving supply chain performance management: A systematic approach to analyzing iterative KPI accomplishment. *Decision support systems*, *46*(2), 512–521.

Calzavara, M., Glock, C. H., Grosse, E. H., & Sgarbossa, F. (2019). An integrated storage assignment method for manual order picking warehouses considering cost, workload and posture. *International Journal of Production Research*, *57*(8), 2392–2408.

Chen, L., Langevin, A., & Riopel, D. (2011). A tabu search algorithm for the relocation problem in a warehousing system. *International Journal of Production Economics*, *129*(1), 147–156.

Choy, K. L., Ho, G. T., & Lee, C. (2017). A RFID-based storage assignment system for enhancing the efficiency of order picking. *Journal of Intelligent Manufacturing*, *28*, 111–129.

CieChańska, O. (2018). Evolution of Make-to-Stock (MTS) production environment management methods–research concept. In *Forum scientiae oeconomia* (Vol. 6, pp. 21–32).

Courtin, P., Grimault, A., Lhommeau, M., & Fasquel, J.-B. (2020). Dynamic Storage Location Assignment Problem at Knapp company: toward Reinforcement Learning? In *Plate-forme intelligence artificielle.*

Dasgupta, A., Poco, J., Wei, Y., Cook, R., Bertini, E., & Silva, C. T. (2015). Bridging theory with practice: An exploratory study of visualization use and design for climate model comparison. *IEEE transactions on visualization and computer graphics*, *21*(9), 996–1014.

Donk, D. P. V. (2001). Make to stock or make to order: The decoupling point in the food processing industries. *International Journal of Production Economics*, *69*(3), 297–306.

Dreyer, H. C., Bjartnes, R., Netland, T., & Strandhagen, J. O. (2008). Real-time Supply Chain Planning and Control–A Case Study from the Norwegian Food Industry. *Proceedings of APMS 2008 in Helsinki, Finland*.

Frazelle, E. H. (2016). *World-class warehousing and material handling.* McGraw-Hill Education.

Göransson, M., Nilsson, F., & Jevinger, Å. (2018). Temperature performance and food shelf-life accuracy in cold food supply chains–Insights from multiple field studies. *Food Control*, *86*, 332–341.

Gu, J., Goetschalckx, M., & McGinnis, L. F. (2007). Research on warehouse operation: A comprehensive review. *European journal of operational research*, *177*(1), 1–21.

Hamdy, W., Mostafa, N., & Elawady, H. (2018). Towards a smart warehouse management system. In *Proceedings of the international conference on industrial engineering and operations management* (Vol. 2018, pp. 2555–2563).

Heragu*, S. S., Du, L., Mantel, R. J., & Schuur, P. C. (2005). Mathematical model for warehouse design and product allocation. *International journal of production research*, *43*(2), 327–338.

Holzapfel, A., Kuhn, H., & Sternbeck, M. G. (2018). Product allocation to different types of distribution center in retail logistics networks. *European Journal of Operational Research*, *264*(3), 948–966.

Jacobs, E., & Mafini, C. (2019). Transactional leadership, supply chain quality and business performance in the fast-moving consumer goods industry. *Journal of Transport and Supply Chain Management*, *13*(1), 1–13.

Janssen, M., Van Der Voort, H., & Wahyudi, A. (2017). Factors influencing big data decision-making quality. *Journal of business research*, *70*, 338–345.

Jeble, S., Kumari, S., & Patil, Y. (2017). Role of big data in decision making. *Operations and Supply Chain Management: An International Journal*, *11*(1), 36–44.

Kao, C.-Y., & Chueh, H.-E. (2022). Deep Learning Based Purchase Forecasting for Food Producer-Retailer Team Merchandising. *Scientific Programming*, *2022*.

Karthik, T., & Prasad, T. R. (2020). SWOT (Strength, Weakness, Opportunities and Threats) Analysis of Fast Moving Consumer Goods (FMCG) Industries in India. *Shanlax International Journal of Commerce*, *8*(1), 92–100.

Kay, M. G. (2015). *Warehousing* (Master's thesis). North Carolina State University.

Kheybari, S., Naji, S. A., Rezaie, F. M., & Salehpour, R. (2019). ABC classification according to Pareto's principle: a hybrid methodology. *Opsearch*, *56*, 539–562.

Koliba, C., Merrill, S. C., Zia, A., Bucini, G., Clark, E., Shrum, T. R., ... Smith, J. M. (2022). Assessing strategic, tactical, and operational decision-making and risk in a livestock production chain through experimental simulation platforms. *Frontiers in Veterinary Science*, 1584.

Krauth, E., Moonen, H., Popova, V., & Schut, M. (2005). Performance indicators in logistics service provision and warehouse management - a literature review and framework. In *Euroma international conference* (pp. 19–22).

Kusrini, E., Novendri, F., & Helia, V. N. (2018). Determining key performance indicators for warehouse performance measurement–a case study in construction materials warehouse. In *Matec web of conferences* (Vol. 154, p. 01058).

Lanza, G., Passacantando, M., & Scutellà, M. G. (2022). Assigning and sequencing storage locations under a two level storage policy: Optimization model and matheuristic approaches. *Omega*, *108*, 102565.

Larose, D. T., & Larose, C. D. (2014). *Discovering knowledge in data: an introduction to data mining* (Vol. 4). John Wiley & Sons.

Lunenburg, F. C. (2010). The decision making process. In *National Forum of Educational Administration & Supervision Journal* (Vol. 27).

Manders, J. H., Caniëls, M. C., & Ghijsen, P. W. T. (2016). Exploring supply chain flexibility in a FMCG food supply chain. *Journal of Purchasing and Supply Management*, *22*(3), 181–195.

Manuele, F. A. (2009). Leading & lagging indicators. *Professional Safety*, *54*(12), 28–33.

Marr, B. (2012). *Key Performance Indicators (KPI): The 75 measures every manager needs to know*. Pearson UK.

Moore, J. (2017). Data visualization in support of executive decision making. *Interdisciplinary Journal of Information, Knowledge, and Management*, *12*, 125.

Muppani, V. R., & Adil, G. K. (2008). Efficient formation of storage classes for warehouse storage location assignment: a simulated annealing approach. *Omega*, *36*(4), 609–618.

Nemtajela, N., & Mbohwa, C. (2017). Relationship between inventory management and uncertain demand for fast moving consumer goods organisations. *Procedia Manufacturing*, *8*, 699–706.

Nettsträter, A., Geißen, T., Witthaut, M., Ebel, D., & Schoneboom, J. (2015). Logistics software systems and functions: an overview of ERP, WMS, TMS and SCM systems. *Cloud computing for logistics*, 1–11.

Ouyang, W., Zhang, Y., Zhu, M., Zhang, X., Chen, H., Ren, Y., & Fan, W. (2019). Interpretable Spatial-Temporal Attention Graph Convolution Network for Service Part Hierarchical Demand Forecast. In *Natural language processing and chinese computing: 8th ccf international conference, nlpcc 2019, dunhuang, china, october 9–14, 2019, proceedings, part ii 8* (pp. 575–586).

Park, S., Bekemeier, B., Flaxman, A., & Schultz, M. (2022). Impact of data visualization on

decision-making and its implications for public health practice: a systematic literature review. *Informatics for Health and Social Care*, *47*(2), 175–193.
Raghunathan, S. (1999). Impact of information quality and decision-maker quality on decision quality: a theoretical model and simulation analysis. *Decision support systems*, *26*(4), 275–286.
Reyes, J., Solano-Charris, E., & Montoya-Torres, J. (2019). The storage location assignment problem: A literature review. *International Journal of Industrial Engineering Computations*, *10*(2), 199–224.
Romsdal, A. (2014). Differentiated production planning and control in food supply chains [PhD dissertation]. *NTNU Open*.
Sadiku, M., Shadare, A. E., Musa, S. M., Akujuobi, C. M., & Perry, R. (2016). Data visualization. *International Journal of Engineering Research And Advanced Technology (IJERAT)*, *2*(12), 11–16.
Scholz, A., & Wäscher, G. (2017). Order Batching and Picker Routing in manual order picking systems: the benefits of integrated routing. *Central European Journal of Operations Research*, *25*(2), 491–520.
Sgarbossa, F., Romsdal, A., Johannson, F. H., & Krogen, T. (2020). Robot picker solution in order picking systems: an ergo-zoning approach. *IFAC-PapersOnLine*, *53*(2), 10597–10602.
Silva, A., Coelho, L. C., Darvish, M., & Renaud, J. (2020). Integrating storage location and order picking problems in warehouse planning. *Transportation Research Part E: Logistics and Transportation Review*, *140*, 102003.
Silva, A., Roodbergen, K. J., Coelho, L. C., & Darvish, M. (2022). Estimating optimal ABC zone sizes in manual warehouses. *International Journal of Production Economics*, *252*, 108579.
Srinivas, S., Rajendran, S., & Ziegler, H. (2021). *Supply Chain Management in Manufacturing and Service Systems*. Springer.
Srividya, V., & Tripathy, B. (2022). Role of big data in supply chain management. In *Innovative supply chain management via digitalization and artificial intelligence* (pp. 43–59). Springer.
Staudt, F. H., Alpan, G., Di Mascolo, M., & Rodriguez, C. M. T. (2015). Warehouse performance measurement: a literature review. *International Journal of Production Research*, *53*(18), 5524–5544.
Sukhochev, A. (2021). *Fresh food forecasting.* Retrieved 2022-11-14, from `https://dslab.ai/demand-forecasting-for-fresh-food`
Tan, Z., Li, H., & He, X. (2021). Optimizing parcel sorting process of vertical sorting system in e-commerce warehouse. *Advanced Engineering Informatics*, *48*, 101279.
Thomopoulos, N. T., & Thomopoulos, N. T. (2016). Distribution Network. *Elements of Manufacturing, Distribution and Logistics: Quantitative Methods for Planning and Control*, 211–228.
Thompson, G. (2010). *What Is Supply and Demand?* Crabtree Publishing. Retrieved from `https://search.ebscohost.com/login.aspx?direct=true&db=nlebk&AN=419759&site=ehost-live&scope=site`
Trienekens, J. H., Wognum, P., Beulens, A. J., & van der Vorst, J. G. (2012). Transparency in complex dynamic food supply chains. *Advanced Engineering Informatics*, *26*(1),

55–65.
Trindade, M. A., Sousa, P. S., & Moreira, M. R. (2022). Ramping up a heuristic procedure for storage location assignment problem with precedence constraints. *Flexible Services and Manufacturing Journal*, *34*(3), 646–669.
Van Den Berg, J. P. (1999). A literature survey on planning and control of warehousing systems. *IIE transactions*, *31*(8), 751–762.
Wang, M., Zhang, R.-Q., & Fan, K. (2020). Improving order-picking operation through efficient storage location assignment: A new approach. *Computers & Industrial Engineering*, *139*, 106186.
Wang, X., & Disney, S. M. (2016). The bullwhip effect: Progress, trends and directions. *European Journal of Operational Research*, *250*(3), 691–701.
Warehouse Management Systems Market Report, 2030. (2023). Retrieved 2023-06-14, from https://www.grandviewresearch.com/industry-analysis/warehouse-management-system-wms-market
Warehouse Management Systems - Where to Start? White Paper. (n.d.). Retrieved 2023-06-13, from https://www.sccgltd.com/wp-content/uploads/Whitepaper-design-November-2022-1.pdf
Wild, T. (2017). *Best practice in inventory management.* Routledge.
Yu, M.-C. (2011). Multi-criteria ABC analysis using artificial-intelligence-based classification techniques. *Expert Systems with Applications*, *38*(4), 3416–3421.

Appendix

A Interview Guide

Generelle spørsmål:

1. Lagerutforming
    - Separerer dere varehuset i soner for ulike produkter?
        - I tillegg til tørrvarer, frys og kjøl?
        - Plasseres lignende varer sammen?
        - Hvilken informasjon baseres denne avgjørelsen på, hvor ofte oppdateres det, og revurderes metoden denne beslutningen?
    - Hvilken rotering av varer praktiseres?
    - Hvor mange varelinjer har dere?
    - Hvor mange varer kommer inn og blir sendt ut fra lager hver dag?
    - Hvor mange vareenheter har dere på lager?
        - Hvilken fordeling utgjør det av tørr, frys og kjøl?
    - Hvilke KPIer har dere for lagerdrift?
        - Fokus på varehåndteringskostnader eller utnyttelse av plass?
    - Er varer bundet til en spesifikk lokasjon, eller plasseres flere varer på samme område?
        - Hvilken informasjon baseres det på, hvem er involvert i beslutningen, hvor ofte oppdateres lokasjonene, og revurderes metoden for dennne beslutningstakingen?
2. Automatisering på lager
    - I hvilken grad er lageret automatisert?
    - Benyttes automatisering for å transportere paller?
    - Benyttes automatisering for å pakke inn paller?
    - Er det noen planer om økning eller reduksjon av automatisering?
3. Arbeidere
    - Hvor mange arbeidere er på lageret samtidig?
    - Hvilke skiftordninger har dere?
    - Er det mye ledig tid?

    - Hva benyttes denne tiden til?

4. Er det mange varer som sendes fra andre distribusjonskanaler/sentrallagere som skal videre til butikker?
    - Er disse varene ferdig pakket ved ankomst?
    - Er det en økning eller reduksjon i antall slike varer?

Spørsmål relatert til valg av varelokasjoner:

1. Hvordan velger dere hvor varer skal plasseres på lager?
    - Er det en modell som regner ut plasseringer?
        - Hvis ja, gjøres det justeringer til dette?
    - Regner dere ut etterspørsel i gitte tidsperioder på egenhånd?
    - Hvor ofte revurderes plassering av varer, hvilken informasjon baseres det på, vurderer dere om det er en god metode for å bestemme varelokasjoner?
        - Dersom dere får inn nye produkter utenom bestemte tidspunkter, hvordan går dere frem for å finne riktig plass til varen?
        - Flytter dere på varer som allerede er blitt plassert på lager dersom varen blir tildelt en ny varelokasjon, eller blir kun nye varer av denne typen plassert på den nye lokasjonen? Når flyttes eventuelt varene?
2. Klassifisering av varer
    - Hvordan bestemmes hvilke varer som er viktigst/har størst omsetning?
        - Hvilken informasjon baseres det på, hvem bestemmer dette, hvor ofte oppdateres det, og revurderes metoden for klassifisering?
        - Hvor plasseres varer som plukkes ofte og varer som plukkes sjeldnere?
    - Plasseres varer som ofte bstilles sammen i nærhet til hverandre?
        - Organiseres lageret likt som butikkenes oppsett, lignende varer på samme områder?
    - Planlegger dere varelokasjoner annerledes for kampanjer?
        - Hvordan forberedes lageret på kampanjer?
3. Etterspørsel
    - Baseres prognoser for etterspørsel på utelukkende historisk data?
        - Hvordan lager dere prognoser, hvilken informasjon brukes, og hvor ofte oppdateres prognosene?
4. Tar dere hensyn til kampanjer når dere vurderer fremtidig etterspørsel?

- Hvordan legges dette inn i prognosene?

5. Beslutningstakere
   - Hvilke beslutningstakere er med på å bestemme varelokasjoner?
   - Er det mye ekspertise og kunnskap på dette området?
     - Bevares ekspertenes kunnskap?
   - Gjøres det analyser utover hva som ligger tilgjengelig i WMS?
     - Hva er resultatet fra eventuelle analyser?
   - Dersom en skulle overta beslutningstaker-rollen i dag, hvor lang tid vil det ta før hen blir god på det?
   - Hva måles beslutningstakere på?
     - Hvordan bestemmer dere om metoden for bestemmelse av varelokasjoner må endres?
   - Hvor oppsøker beslutningstakere informasjon for å bestemme varelokasjoner?
6. Hvis du kan ønske deg en funksjonalitet fra systemet som kan hjelpe med beslutninger knyttet til varelokasjoner - hva ser du for deg da?

NTNU

Norwegian University of
Science and Technology