Reconfiguration of a Pre-Assembly Warehouse Based on Context

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MASTER'S THESIS

Reconfiguration of a Pre-Assembly Warehouse Based on Context

A Design Science Study at the Global Transport Solutions Company Scania

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Acknowledgments

This thesis was written during the spring of 2024 as a final project of our master's degree in Industrial Engineering and Management with a specialization in Supply Chain Management at the Faculty of Engineering at Lund University. The project was conducted as a design science study, and the aim was to propose a recommendation on a warehouse configuration for one of Scania AB's pre-assembly warehouses based on its context.

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Victoria Lindwert and Matilda Muotka

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Abstract

Title	Reconfiguration of a pre-assembly warehouse based on context - a design science study at the global transport solutions company Scania.
Authors	Victoria Lindwert and Matilda Muotka.
Supervisor	Monica Mora, Division of Mechanical Engineering Sciences, Lund University.
Problem description	Scania is planning on phasing out their DL engine in the future. This puts the warehouse in a new context, especially due to changes in product characteristics and demand profile. Furthermore, the warehouse is experiencing capacity issues, and the current configuration will not be able to meet the capacity need. Therefore, the main problem that this thesis aims to solve is how to reconfigure Scania's pre-assembly warehouse based on its future context, to meet demand efficiently and cost-effectively.
Purpose	The purpose is to recommend a configuration of Scania's pre-assembly warehouse suitable for when the phaseout of the DL engine has been realized, considering the context of the warehouse.
Objectives	**RO1:** Identify the warehouse context based on relevant contextual factors, and which configuration element options are most suitable based on this. **RO2:** Develop a recommendation on how to configure the warehouse given RO1.
Methodology	The design science research strategy is applied, and the research design consists of five steps: explicite problem, define requirements, design and develop artefact, demonstrate artefact, and evaluate artefact.
Conclusions	The thesis resulted in suitable options for relevant configuration elements, based on the warehouse's expected future context. These were used to develop a final warehouse configuration recommendation for Scania, which meets the expected capacity need, ensures short travel distances, and has a limited congestion risk.
Contribution	This thesis has been a complete elaboration between the two authors. Each author has been involved in every part of the process and contributed equally.

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Definitions and Abbreviations

DL	One of Scania's main engines, planned to be phased out in the future
DW	One of Scania's main engines
PS	One of Scania's main engines
V8	One of Scania's main engines
CBS	Class Based Storage
DS	Design Science
FIFO	First-in-first-out
SKU	Stock Keeping Unit
WMS	Warehouse Management System
——	
XX	Numbers hidden due to confidentiality reasons
20YY	The year of the phaseout of the DL engine, hidden due to confidentiality reasons

Chapter 1

Introduction

This chapter introduces the thesis and the problem it aims to solve. It begins with a presentation of warehouses and their typical challenges, followed by a formulation of the problem, the purpose, and the research objectives. The chapter is concluded with scoping the thesis by defining the studied system and stating the delimitations.

1.1 Background

Warehouses greatly contribute to fulfilling customer service and play a crucial role in the success or failure of businesses (Dissanayake & Rupasinghe 2021; Frazelle 2002). Therefore, warehouse efficiency can be considered a strategic weapon within an organization (Jermsittiparserta et al. 2019). Especially during current challenging times, with global instability, shifts in customer demand, and supply chain disruptions, it is critical for companies to maintain efficient warehouses to stay competitive in their supply chains (Albert et al. 2023). Warehouses also drive a lot of the logistics costs for companies (Dissanayake & Rupasinghe 2021). Due to this, warehouses do not only have to be efficient but also cost-effective. This requires, amongst other factors, effective utilization of floor space (Raghuram & Arjunan 2010).

An umbrella term used to describe warehouse operations, design, and resources is warehouse configuration (Kembro et al. 2018). Warehouse configuration elements include, but are not limited to, put away policies, picking methods, the physical layout of the warehouse, and the storing and handling equipment used. There are several options for each configuration element, and decisions made about these are critical since they affect the efficiency and cost-effectiveness of the warehouse. Rouwenhorst et al. (2000) emphasize that warehousing costs are largely determined in the design phase.

Much of the warehouse configuration research is based on distribution warehouses and homogeneous warehouses where the goods stored are similar or identical in some ways (Albert et al. 2023). This is not the case for most real-world companies. Therefore, it is not surprising that many companies struggle to turn the theory on warehouse configuration into real warehouses (Albert et al. 2023). They tend to rather base their decisions on rules-of-thumb or simplistic ratios (Bartholdi & Hackman 2019). This might not result in the most efficient and cost-effective configuration, thereby limiting the success of the business. Configuring a warehouse is, however, a complex task (Rouwenhorst et al. 2000). Many interrelated design aspects must be considered simultaneously, and a typical challenge is to decide between several feasible alternatives (Dissanayake & Rupasinghe 2021; Rouwenhorst et al. 2000). Adding to the complexity is also the specific context that the warehouse operates in (Kembro & Norrman 2021). There is no generic answer to what warehouse configuration is the best. However, adapting the configuration to fit the warehouse context can enhance warehouse performance (Faber et al. 2018; Kembro & Norrman 2021). In practice, this means that warehouse performance increases when structures and processes are aligned with their environment (Kembro & Norrman 2021). Some examples of contextual factors that together form the context of the warehouse are the type and role of the studied warehouse, product characteristics, order characteristics, customer characteristics, and demand profile (Bartholdi & Hackman 2019; Kembro & Norrman 2021; Onstein et al. 2018; Rouwenhorst et al. 2000).

Inspired by the above presented conclusions from warehouse research, this thesis aims to recommend a theoretically driven warehouse configuration of a pre-assembly warehouse, based on context. This entails identifying the relevant contextual factors and understanding which configuration elements they affect. With this knowledge, the context of the warehouse can be understood, and that, in turn, helps guide which configuration element options to choose. To put this research into a real-life context, a case company is used.

1.2 Case Company

The case company for this thesis is Scania, which is a global transport solutions company, producing and selling trucks, buses, and engines for heavy transport, industry, and the marine field, combined with a product-related range of services. The company was founded in 1900 in Malmö, Sweden and since 2015, they are part of the TRATON Group together with brands such as Navistar and MAN (Traton 2024). Scania has over 50000 employees in more than 100 countries across the globe (Scania 2024). This thesis focuses on Scania's pre-assembly warehouse that supplies the engine assembly with components. The warehouse is located in Södertälje, where the company also has its headquarters. The items in the warehouse range from engine blocks and crankshafts to fuel injectors and screws, but the stock keeping units (SKUs) stored are limited to different variants of pallets and boxes. They are handled as either pallets, boxes, cartons, or pieces.

1.3 Problem Statement

In the future, one of Scania's main engines, the DL engine, is being phased out and the assembly line is being decommissioned. Together with the decommissioning, the production rate of another main engine, the DW engine, is planned to increase. Due to these changes, the context of the warehouse will change, since the number of orders, number of SKUs, picking frequency, and so on, will be different. Furthermore, the capacity need per SKU type will change, however, the overall capacity need is not expected to decrease significantly. Today, the warehouse is not sufficiently configured to be able to store all SKUs needed based on the set coverage time and fill rate. Therefore, the main problem that this thesis aims to solve is how to configure Scania's pre-assembly warehouse based on the warehouse context, to meet future demand efficiently and cost-effectively. Hereafter, the year of the phaseout will be referred to as year "20YY". In Figure 1.1 below, a visualization of the situation and problem is presented.

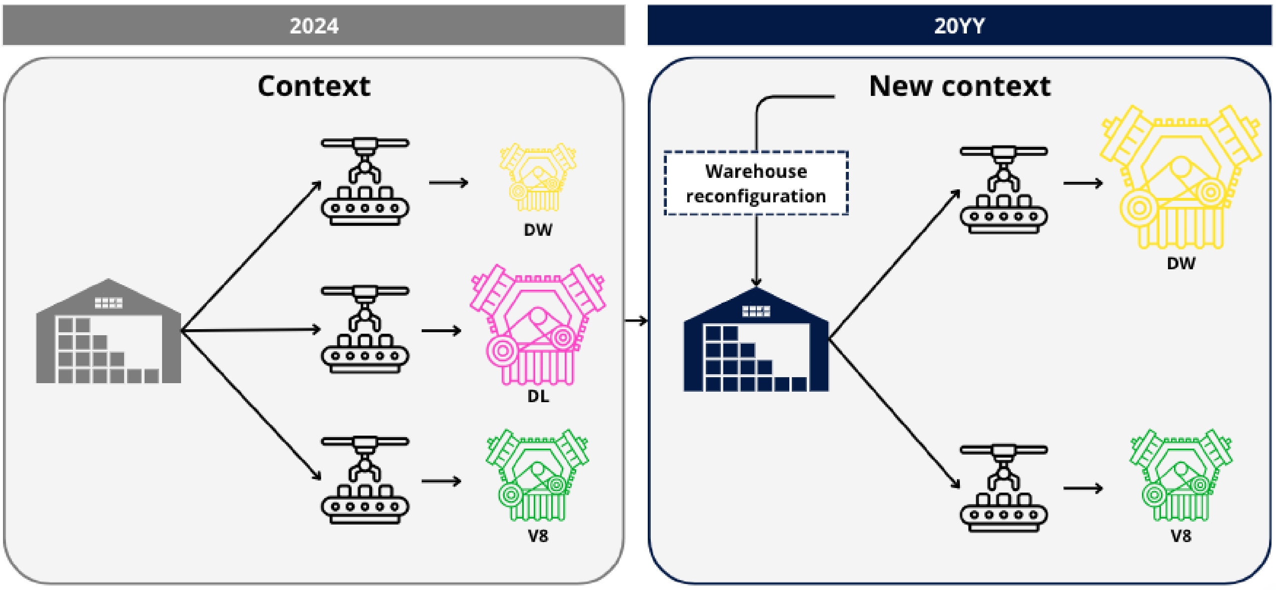


Figure 1.1: A visualization of the situation and problem.

1.4 Purpose and Research Objectives

The purpose of the thesis is to *recommend a configuration of Scania's pre-assembly warehouse suitable for when the phaseout of the DL engine has been realized, considering the context of the warehouse.* To fulfill the purpose of the thesis, two main research objectives are addressed, which guide the project.

RO1: Identify the warehouse context based on relevant contextual factors, and which configuration element options are most suitable based on this.

This objective entails three parts. First, the contextual factors that are relevant for the warehouse and how they influence different configuration elements are understood, together with what configuration element options are suitable in which context. Second, the overall context of the warehouse is identified by analyzing the contextual factors. Third and final, the context is matched with the most suitable configuration element options.

RO2: Develop a recommendation on how to configure the warehouse given RO1.

In this objective, the suitable configuration element options from RO1 are put together into a final warehouse configuration recommendation. To make the configuration realizable, trade-offs might have to be made. The final recommendation suggests what the warehouse design and resources should look like, such as aisle configuration layout and lane depth. It also recommends how the warehouse operations, such as put away, picking, and shipping, should be performed.

1.5 Studied System

A visualization of the studied system is presented in Figure 1.2 below. As can be seen, the thesis is limited to focus from the point where a SKU enters the walls of the pre-assembly warehouse to the point it is delivered to the engine assembly. Thus, the goods receipt is not part of the scope. Furthermore, activities concerning inventory control, reorder points, and external factors beyond the warehouse facility and its operations are excluded from the investigation.

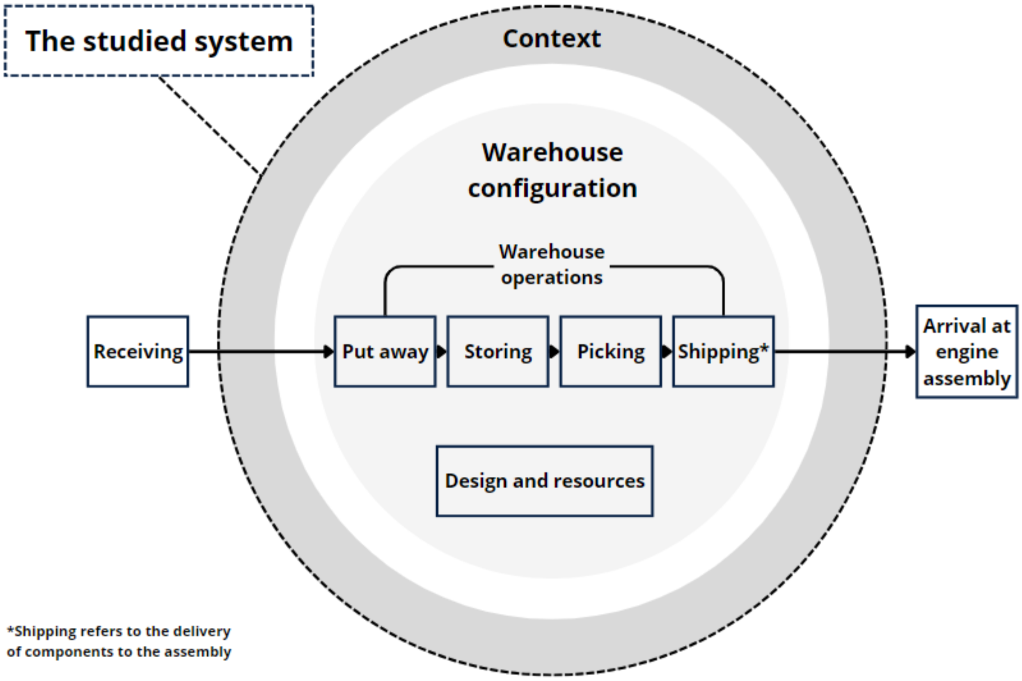


Figure 1.2: A visualization of the studied system. All factors and activities within the dashed line are part of the scope.

In addition to the scope of the project, the following delimitations were established together with the case company:

- The overall capacity need that the future warehouse must meet is set, and it is assumed that this remains from the point in time when the DL engine has been phased out.
- There are no possibilities to expand the warehouse, and its shape and dimensions will remain as they are today.
- The storage areas for carton picked SKUs and piece picked SKUs are not to be reconfigured, however they should be included in the final recommendation.

- It can be assumed that the information systems, specifically the warehouse management system (WMS), can support the suggested configuration.
- Automation solutions are not to be investigated.
- Due to the limited project time of 20 weeks, an implementation plan or a live implementation is not part of the project.

1.6 Thesis Structure

Method	This chapter presents the research strategy, research design, data collection process, and data analysis process used in the thesis to ensure research quality.
Frame of Reference	This chapter introduces relevant warehousing theory, which for this thesis concerns contextual factors, warehouse design and resources, and warehouse operations. This chapter also presents the overall analytical framework used in the thesis.
Empirical Findings	This chapter presents the empirical findings obtained through interviews, observations, and secondary data provided by Scania. Together with the frame of reference, the empirical findings function as input to the analysis.
Analysis	This chapter identifies the warehouse context and analyzes which configuration element options are most suitable based on warehousing theory and the identified context.
Recommendation	This chapter develops the final recommendation by putting together the configuration element options chosen in the analysis and making compromises between these. The chapter also highlights the recommendation's practical applicability and discusses the recommendation's risks and sensitivities.
Conclusions	This chapter summarizes how the purpose of the thesis and the research objectives have been met. It also discusses limitations and concludes what areas could be investigated in future research.

Chapter 2

Method

This chapter describes the method chosen to fulfill the purpose of the thesis. First, the strategy and design of the research are presented, showing what activities were made during the research. Second, the method for, and process of, collecting and analyzing data are presented. Third and last, it is described how the research quality was considered for the thesis.

2.1 Research Strategy

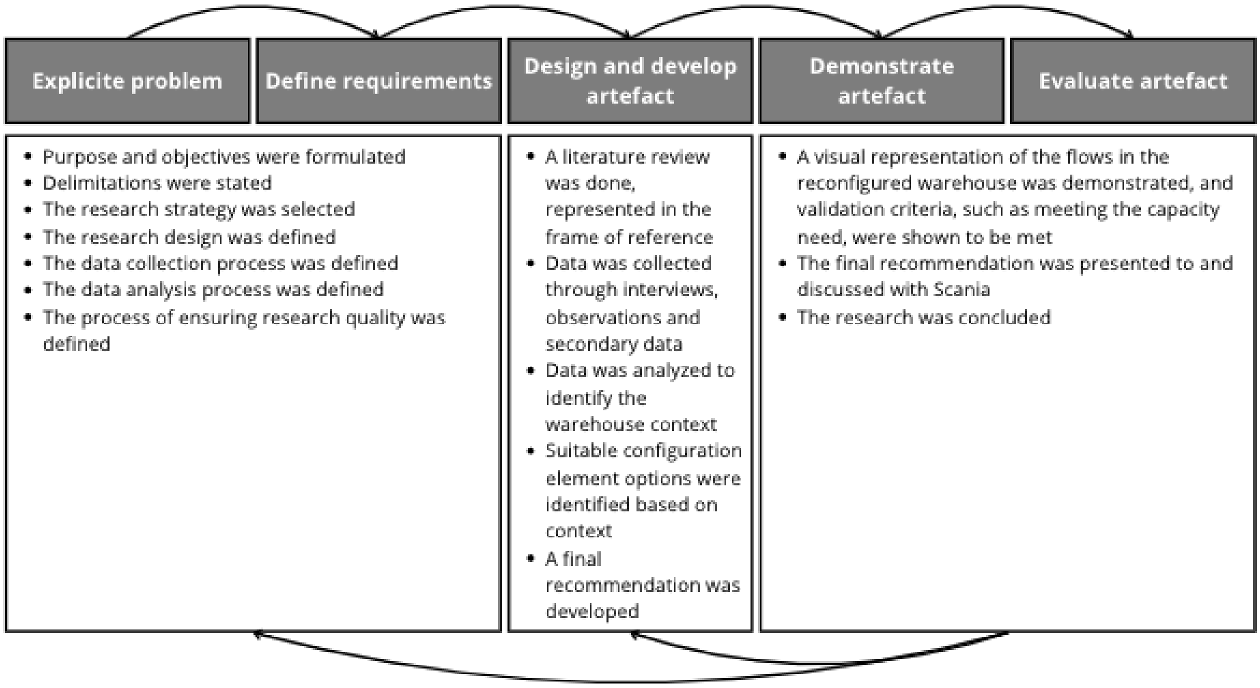
To reach the thesis' research objectives, the design science (DS) research strategy was used. The DS strategy met the dual nature of the thesis; to both provide a solution for a real-world company and contribute with research that can be used beyond the case company. Furthermore, the feasibility of performing a DS study both in an academic environment and in an organizational context justified the choice of research strategy.

Kembro et al. (2022) state that the DS research strategy is gaining popularity within supply chain and operations management research, and in contrast to just gathering theoretical knowledge, a DS study aims to solve real-world problems based on "exploration through design" (Holmström et al. 2009). The essence of DS research is changing a system from an as-is state to a desired state, which is done by creating something new, also called an artefact (Romme & Dimov 2021). The artefact is the main outcome of DS research and does not have to be a physical object (Müller & Thoring 2011). It can for example be a technology, management practice, or design principle (Romme & Dimov 2021). The DS research strategy is best applied when the study is driven by real-world operations management problems and opportunities, and when actions, processes, or systems are to be designed (van Aken et al. 2016). Furthermore, DS research helps bridge the gap between theory and practice by creating artefacts that provide input material to explanatory researchers (Holmström et al. 2009). In this thesis, the system changed was Scania's pre-assembly warehouse, and the artefact created was a warehouse configuration based on the warehouse context, which was identified by analyzing contextual factors.

Despite the advantages of DS studies, a key issue for DS research within operations management highlighted by van Aken et al. (2016) is the need to deal with social aspects. Without considering them, the risk is that research quality is not ensured. This was especially relevant for this thesis since the warehouse was highly manual and had many social components. Due to this risk, the case study research was considered an alternative strategy. However, this type of study did not fit the objectives of the thesis as well as DS did. The main reason was because while DS research has the objective to design and develop artefacts in a real-world setting (Romme & Dimov 2021), case studies usually aim to explore, describe, explain or predict an issue, and illuminate why certain decisions were made and what the result of these were (Yin 2003). Because of this mismatch between the typical purpose of a case study research and this thesis' purpose, it was concluded that DS was the most suitable research strategy for the thesis. Nonetheless, the research strategy functioned more as a guideline to meet the purpose of the research, rather than considered a set of strict rules, following what has been suggested by Saunders et al. (2009).

2.2 Research Design

After deciding on the research strategy, a research design inspired by Johannesson and Perjons (2021) was developed. The design consisted of five steps in total: (1) explicite problem; (2) define requirements; (3) design and develop artefact; (4) demonstrate artefact, and; (5) evaluate artefact, which were moved between iteratively. The full research design is visualized in Figure 2.1.



- Purpose and objectives were formulated
- Delimitations were stated
- The research strategy was selected
- The research design was defined
- The data collection process was defined
- The data analysis process was defined
- The process of ensuring research quality was defined

- A literature review was done, represented in the frame of reference
- Data was collected through interviews, observations and secondary data
- Data was analyzed to identify the warehouse context
- Suitable configuration element options were identified based on context
- A final recommendation was developed

- A visual representation of the flows in the reconfigured warehouse was demonstrated, and validation criteria, such as meeting the capacity need, were shown to be met
- The final recommendation was presented to and discussed with Scania
- The research was concluded

Figure 2.1: The overall structure of the research design for this thesis, including what activities were made during each step, inspired by Johannesson and Perjons (2021).

Regarding the demonstration and evaluation of the artefact, these steps can be done with numerical evaluation methods first after the reconfiguration has been realized, which happens after the thesis has been concluded. However, to still follow the DS research strategy, the final recommendation was demonstrated and evaluated through a presentation and discussion with Scania. Thanks to the dynamic research design, feedback from the evaluation was brought into the design and development of the artefact, since iterations between the different steps were made.

2.3 Data Collection

Many different types of data had to be collected to be able to meet the objectives of the thesis. To structure the collection process and get an overview of what information needed to be gathered, a list of data to collect was developed. The list was created by first identifying the business requirements and design constraints for the project, which was done during the first two steps of the research design. During these steps, some project-specific key facts were identified, such as customer delivery requirements and safety requirements. In addition, the requirements and constraints helped guide the literature review, in the way that they highlighted which fields within warehousing theory to focus on. Via the literature review, relevant contextual factors and general key facts that need to be understood in any warehouse configuration project were identified. The general key facts to learn about a warehouse were inspired by Bartholdi and Hackman (2019), who developed the list based on the idea that measuring warehouse activity should be part of every warehouse project. Some key facts presented by the authors were not relevant to this research, why they were not included. Together with the already identified project-specific key facts, and the contextual factors, the general key facts constituted the foundation for the data collection process.

The data collection process began with leading interviews with Scania employees from the warehouse, the engine assembly, and the central logistics team. Second, data was collected through observations of the current warehouse and its processes. Third, data was collected in the form of extracted files from information systems, such as order data, SKU data, and inventory data. All collected data was then analyzed to identify the warehouse context. The context was then synthesized and matched with suitable configuration element options, according to the theory presented in the literature review. This eventually led to a warehouse configuration recommendation. An overview of the data collection process, and its role in developing the recommendation, is presented in Figure 2.2.

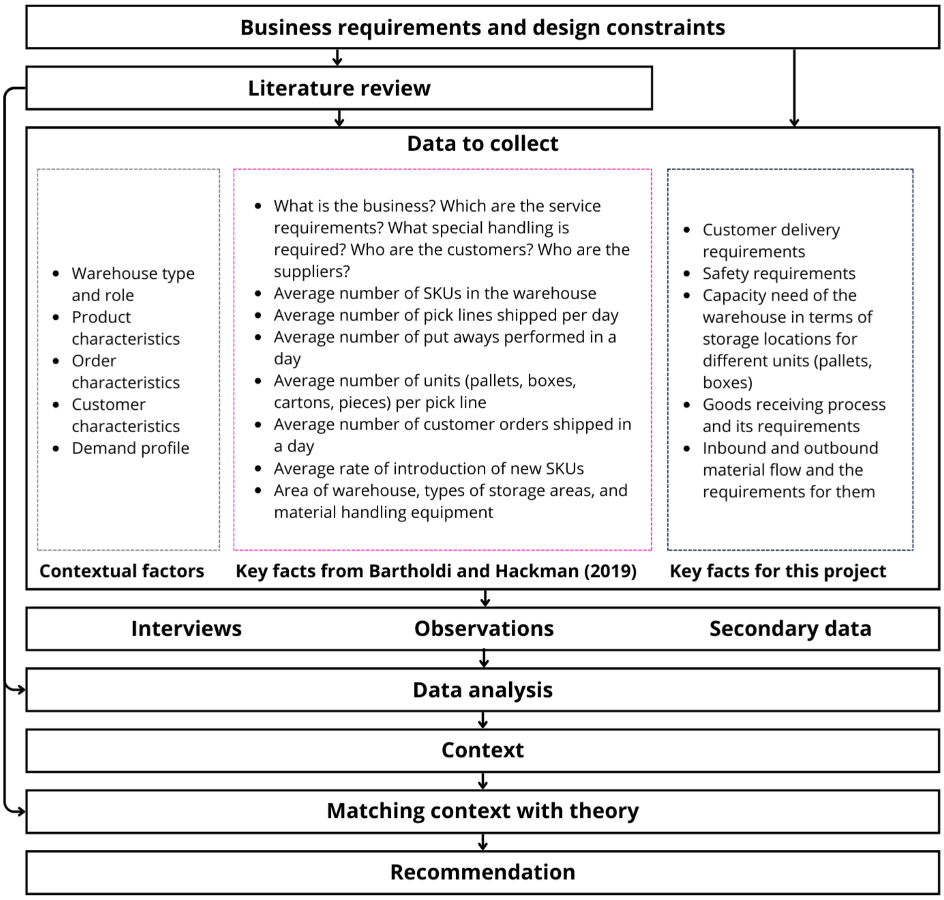


Figure 2.2: An overview of the data collection process in the thesis.

2.3.1 Literature Review

A literature review was conducted, following five steps suggested by Rowley and Slack (2004): (1) scanning; (2) note-taking; (3) structuring; (4) writing, and; (5) building the bibliography. The literature review helped build a fundamental understanding of the existing knowledge base, and the common research methods, within the warehouse configuration field, in line with Rowley and Slack (2004) and Dresch et al. (2014).

For scanning, databases like LUBSearch and Google Scholar were used, and further literature was found through cross-referencing. The majority of sources considered were books and articles from academic journals. To effectively distill knowledge, keyword searches together with advanced search functions, such as boolean operators, were used. Some keywords used were: warehouse, operations, design, configuration, automotive, product allocation, storage allocation, picking, and put away. To comply with the DS research strategy, the literature considered had researched and tested solutions to problems that this thesis aimed to solve (Dresch et al. 2014). During note-taking, the texts were annotated and stored for easy retrieval, key points were summarized, and sources were cited. The reference manager Zotero was used to create a common repository and enable effective sharing of knowledge and findings. The bibliography, which lists the sources referred to in the literature review, was built throughout all of these steps, strictly following the Harvard referencing system.

2.3.2 Interviews

A set of semi-structured interviews were conducted with different Scania employees. Dresch et al. (2014) stress that in DS research, the researchers must take all kinds of measures to get a thorough understanding of the problem that the artefact aims to solve, and interviews are, according to Denscombe (2010), well-suited for delving into complex phenomena. In semi-structured interviews, the interviewer has a list of issues to discuss but asks open-ended questions leaving room for the interviewee to elaborate on the answers (Denscombe 2010). A summary of the conducted interviews is presented in Table 2.1. Furthermore, the interview guide can be found in Appendix A.

Table 2.1: A list of all conducted interviews, including attendees and the data collected during each.

Attendees	**Data collected**
Group leader logistics development	Warehouse type and role, the core business, the service requirements, the customers, the suppliers, special handling needed
Project manager engine assembly	Customer characteristics, customer delivery requirements
Project manager DEPA	Average rate of introduction of new SKUs
Supply chain developer	Average number of SKUs in the warehouse, capacity need of the warehouse
Project manager logistics	The information system's functionalities
Logistics developer L	Seasonality trends, affinity possibilities, average number of SKUs in the warehouse, current capacity of the warehouse, material handling requirements
Material handler G	How the receiving operations work
Logistics developer G	Average inbound volume in a day
Workshop technician I	How the put away operations work
Logistics developer P	How the operations work for boxes, piece picked SKUs and carton picked SKUs, what storage and handling equipment are used for this, average number of put aways per day and average number of units per pick list
Logistics developer F	Constraints in the facility, types of storage areas, how the picking and shipping operations work for pallets, storage and handling equipment used for pallets, safety requirements, average number of put aways per day, and average number of units per pick list
Workshop technician F	How the picking and shipping operations work for pallets

The overall aim of the interviews was to identify the context of the warehouse, by understanding the contextual factors, and the project-specific and general key facts. In addition, the interviews allowed the warehouse employees to highlight information not identified in the literature, observations, or secondary data. Such information could be the need for wider aisles than standard, due to the varying truck driving skills of the workforce. The interviews did not directly guide the warehouse configuration, but rather functioned as input to the context identification. This, in turn, could be used to decide on suitable configuration element options.

The interviews were designed according to advice by Voss et al. (2002). First, the interviewers gained a foundational understanding of the topic discussed. Thereafter, a protocol was created to keep track of who to interview and what questions to ask. During the interviews, the interviewers stayed unbiased and focused on asking good questions, listening to the answers, and interpreting them. Both thesis authors took part in all interviews where one led the interview and the other one took notes.

2.3.3 Observations

A combination of structured and direct observations was employed during this thesis to, just like interviews, help identify the warehouse context. The observations complemented the interviews by providing access to first-hand knowledge, as recommended by Denscombe (2010). Structured observations is a common observation method, and is when the researcher observes the phenomenon from the sideline (Denscombe 2010; Johannesson & Perjons 2021). Direct observations, on the other hand, entail collecting data by observing processes, leading meetings, or similar, which can be more and less structured (Voss et al. 2002). The first let the researchers study the warehouse in its natural setting, and the second provided data where it was lacking. A list of all conducted observations can be seen in Table 2.2.

Table 2.2: A list of all conducted observations, including attendees and the data collected during each.

Description of observation	**Attendees**	**Data collected**
Tour of engine assembly	Project manager engine assembly	The core business, the customers, and service requirements
Engine assembly receiving process	Project manager engine assembly	Customer delivery requirements
Facility dimensions	Logistics developer	Area of warehouse and types of storage
Tour of warehouse	Logistics developer x2 & Team leader logistics development	The warehouse role, area of the warehouse, types of storage areas, material handling equipment
Tour of warehouse goods receiving area	Material handler	Goods receiving process, and suppliers
Warehouse inbound and put away process for all separate storage areas	Logistics Developer x4	Inbound material flow and its requirements
Warehouse picking and outbound process for all separate storage areas	Logistics Developer x4	Outbound material flow and its requirements

2.3.4 Secondary Data

To have all the key facts about the warehouse necessary to identify the context and thereby be able to recommend a high-performing warehouse configuration, certain secondary data had to be gathered to complement the data collected from interviews and observations. The secondary data was collected in the form of Excel sheets, data files extracted from Power BI, and similar, with the help of Scania employees. Secondary data was preferred over primary data due to its availability, which better suited the thesis' time constraints. Similar to interviews and observations, secondary data was used to understand the context, but not directly guide the warehouse configuration. A list of the collected secondary data is presented in Table 2.3.

Table 2.3: Secondary data gathered from the case company, including what information the data provided, and what specific data points were retrieved.

Description of data file	**Data collected**	**Key data points**
SKU data	Average number of SKUs in the warehouse, and their characteristics	Size, weight, unit load, and customer per SKU
Order data	Average number of customer orders shipped in a day, average number of pick lines shipped per day, average number of units per pick line	Customer, time of order, and time of pick per SKU
Inventory profile	Seasonality trends, (future) average number of SKUs in the warehouse	Active SKU range and estimated demand for each item

2.4 Data Analysis

The thesis recommended a warehouse configuration based on the warehouse context, which was identified through the analysis of relevant contextual factors. Therefore, the unit of analysis was contextual factors influencing the warehouse configuration elements. To have a realistically sized analysis, only the most relevant contextual factors were analyzed. To decide which contextual factors were relevant, a list with many different contextual factors mentioned in literature was developed. Thereafter, several measures were taken to weed out which were relevant. For instance, some contextual factors were immediately deemed irrelevant due to the scope of the research, for example, financial factors were not included as a contextual factor since this thesis does not investigate the costs of the configuration. Furthermore, the business requirements and design constraints helped understand which configuration elements were more or less relevant in this project. This, in turn, helped understand which contextual factors were relevant to include in the analysis. For example, the facility and receiving area are not to be changed, so there was no need to deeply analyze the inbound volume, which can be attributed to the contextual factor volume. However, storage allocation method and picking method are key configuration elements in this warehouse, and they are affected by the picking frequency and order size, attributes which belong to the contextual factors demand profile and order characteristics. Therefore, the contextual factor volume was not considered relevant, while demand profile and order characteristics were. With a few iterations like this, it became clear that there were five contextual factors that had to be understood to be able to perform a valuable analysis and ultimately complete the warehouse configuration recommendation.

When the relevant contextual factors were identified, the quantitative and qualitative data were analyzed to identify the warehouse context. The data types were analyzed differently, as suggested by Saunders et al. (2009), however, the conclusions were integrated to meet the research objectives and develop the recommendation. The analytical technique used to perform the initial exploration of the data and the analysis of the data was pattern matching, which originates from case study research (Yin 2003). The logic behind pattern matching is to compare if two patterns match each other (Hak & Dul 2009). In Table 2.4, the five-step process used for data analysis in this thesis is presented.

Table 2.4: The five main stages of data analysis in this research study, inspired by the framework presented by Denscombe (2010).

Stages	**Quantitative data**	**Qualitative data**
Data preparation	Cleaned and categorized the data, and converted certain numbers to represent the 20YY situation	Summarized and rewrote notes
Initial exploration of the data	Looked for obvious trends and patterns, and validated the initial findings	Looked for obvious recurrent themes and patterns, and asked clarifying questions
Analysis of the data	Further analyzed the data, for example by doing activity profiling, and compared it to notes from all interviews and observations	Compared notes from all interviews and observations with each other, and with the insights from the analysis of quantitative data
Presentation and display of the data	Presented the findings in distribution graphs, tables, figures, and text	Presented the findings in tables, figures, and text
Validation of the data	Checked the findings with the case company	Checked the findings with the case company

In this case, the quantitative data was in the form of Excel files, screenshots from Power BI dashboards, and other similar data files. Each file was cleaned and categorized by, for instance, deleting irrelevant columns, improving the format, and unifying different files. For example, it was made sure that both the order data and SKU data had the column "item number" formatted identically so that they could be compared and analyzed together in Excel. All quantitative data was based on historical data, or forecasts for the near future, however, the numbers were converted in suitable ways agreed with Scania to represent the situation when the DL engine has been phased out. For instance, each SKU was mapped to what customer it belonged to, and in the case of a SKU only belonging to DL, it was deleted from the SKU range. The SKUs belonging to other customers were kept in the SKU range, and their demand, which, amongst other factors, affects picking frequency and the capacity need, was scaled towards the expected number of produced engines in the year of the DL phase-out.

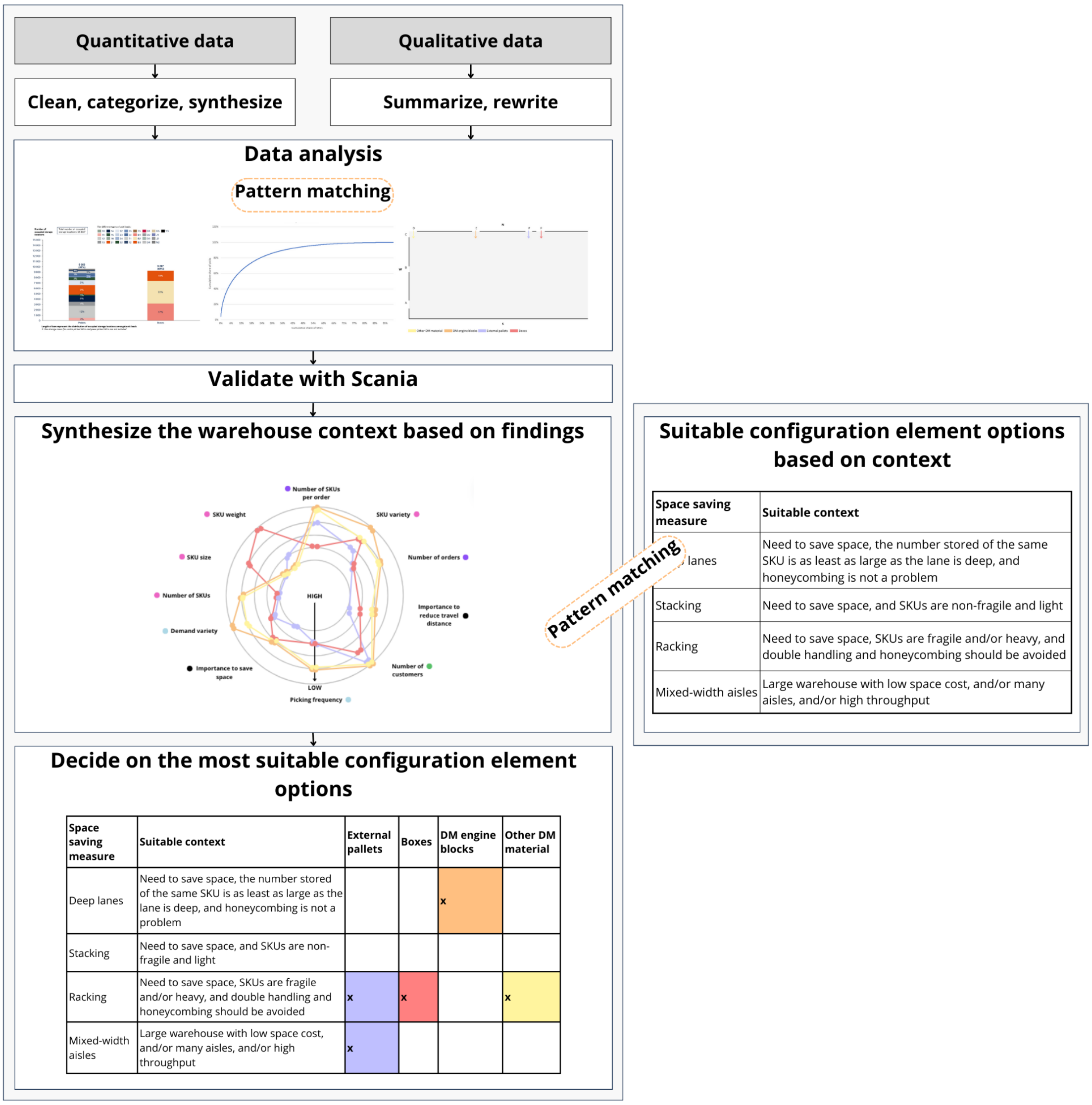
After the data preparation, statistical analyses were made by developing distributions and graphs showing, for instance, the different unit loads expected to be stored in the warehouse, and the number of pick lines per order. This was done to reveal patterns in data. When the patterns were understood, some initial conclusions were drawn, for instance, the number of SKUs to be handled in the warehouse, per customer and SKU type.

Having performed the initial exploration of the quantitative data, a more thorough analysis was done by, amongst other tactics, activity profiling. The reason behind doing this was that research highlights that such an analysis is a valuable tool when designing warehouses (Bartholdi & Hackman 2019). Furthermore, ABC analyses were made, both on customer level and per storage area. An ABC analysis categorizes SKUs in the warehouse into three different categories: A, B, and C, depending on how large a share of total picks the SKUs are responsible for.

The qualitative data analysis was very similar to the quantitative data analysis, however, the data was in the form of interview notes and notes taken during observations, not extracted from information systems. First, the recurrent themes and patterns were found by matching what had been highlighted in many interviews and observations. Second, the findings were compared to the results from the quantitative data analysis. Thereafter, some key findings were presented, for example in the form of maps showing the flows in the warehouse.

When the analysis of the quantitative and qualitative data was finished, and the findings were presented and visualized in various forms, they were validated with Scania via meetings and discussions.

Having gathered a lot of information on the warehouse through the analysis of quantitative and qualitative data, the next step was to synthesize the results to understand the warehouse context. To do so, inspiration was taken from an article published by Kembro and Norrman (2021), in which they introduce a way of mapping a company's contextual factors to get an overview of the company's contextual profile. A similar mapping was done in this thesis, as a first step in the analysis chapter. Having identified the warehouse context through the mapping, pattern matching was used to match the context with the most suitable options for relevant configuration elements, based on theory. By finding matches between empirical findings and the predicted findings based on literature, the internal validity of the research was strengthened (Yin 2003). The completion of this analysis led to the first research objective being fulfilled and was used as input for the second research objective, in which the warehouse configuration recommendation was developed. An overview of the data analysis process can be seen in Figure 2.3.



Space saving measure	Suitable context
lanes	Need to save space, the number stored of the same SKU is as least as large as the lane is deep, and honeycombing is not a problem
Stacking	Need to save space, and SKUs are non-fragile and light
Racking	Need to save space, SKUs are fragile and/or heavy, and double handling and honeycombing should be avoided
Mixed-width aisles	Large warehouse with low space cost, and/or many aisles, and/or high throughput

Space saving measure	Suitable context	External pallets	Boxes	DM engine blocks	Other DM material
Deep lanes	Need to save space, the number stored of the same SKU is as least as large as the lane is deep, and honeycombing is not a problem			x	
Stacking	Need to save space, and SKUs are non-fragile and light				
Racking	Need to save space, SKUs are fragile and/or heavy, and double handling and honeycombing should be avoided	x	x		x
Mixed-width aisles	Large warehouse with low space cost, and/or many aisles, and/or high throughput	x			

Figure 2.3: An overview of the data analysis process in the thesis.

2.5 Research Quality

This thesis considered four criteria for research quality, based on the theory discussed by Gibbert et al. (2008). These criteria were originally dedicated to case study research, but since there are many similarities between case studies and problem-solving research such as DS research (Näslund et al. 2010), they were used as inspiration when evaluating the research quality of this thesis. The criteria are presented in Table 2.5 below. In the table, the measures taken to increase the thesis' research quality are also shown.

Table 2.5: The four criteria for research quality, where in the research process they were most relevant, and measures taken to increase the research quality in this thesis, inspired by Gibbert et al. (2008).

Concept	**Definition**	**Main part of the research process**	**Measures taken to increase quality**
Construct validity	The quality of the conceptualization or operationalization of the relevant concept, meaning to the extent to which a procedure leads to an accurate observation of reality	Data collection	Used multiple data collection strategies and data sources, and presented a clear chain of evidence
Internal validity	The causal relationships between variables and results	Data analysis	Based the recommendation on logic models, and used pattern matching
External validity	The extent to which the findings of the study can be applied to other settings or conditions, beyond the specific context in which the study is conducted, in other words, the "generalizability" of the research study	Research design	Based the warehouse configuration recommendation on warehousing theory, and created a general analytical framework that can be used outside the case company as well
Reliability	The absence of random error, meaning that other researchers arrive at the same conclusions by following the same research steps	Data collection	Documented the research process, the data, and the documents used in the research

The construct validity in this report was ensured by using multiple sources. The collected data came from several interviews, observations, and secondary sources, as well as from a literature review where multiple sources were considered. By using several channels of information, both in terms of people providing the data and the types of data, a broader perspective on the situation could be gained. Furthermore, the information from the data collection was continuously checked with Scania to ensure that it was understood and interpreted correctly. Moving on, internal validity was considered in the data analysis step by matching patterns both within the collected empirical data as well as with the theory presented in the frame of reference. The internal validity was also supported by using logic models when developing the warehouse configuration recommendation. In terms of external validity, the results can be generalized thanks to the warehouse configuration recommendation being based on warehousing theory, and having created a general analytical framework that can be used outside the case company as well. Finally, regarding reliability, this research's results would likely be achieved again if the research was repeated since the process was documented. For interviews and observations, protocols were used to help structure and remember information. Furthermore, all data collected was stored digitally, in common folders, in order to facilitate finding the information when wanting to analyze it.

Chapter 3

Frame of Reference

The frame of reference chapter begins by introducing relevant theory on contextual factors and warehouse configuration elements and is concluded by presenting an analytical framework, which shows the analytical process and structure of the research. Note that warehouse configuration is divided into warehouse design and resources and warehouse operations, based on the definition by Kembro and Norrman (2021).

3.1 Contextual Factors

Each warehouse operates in its specific context, and the importance of context has been highlighted in warehouse research (Faber et al. 2018; Kembro et al. 2018). Depending on the situation, certain contextual factors might be more or less important to consider (Kembro & Norrman 2021). Nonetheless, the most influential contextual factors should be considered when configuring a warehouse to reach high performance (Faber et al. 2018; Kembro & Norrman 2021). In their research, Kembro and Norrman (2021) present a contingency framework in which they stress how the match between contextual factors and warehouse configuration affects warehouse performance. This framework has been adapted and used in this thesis and can be seen in Figure 3.1 below.

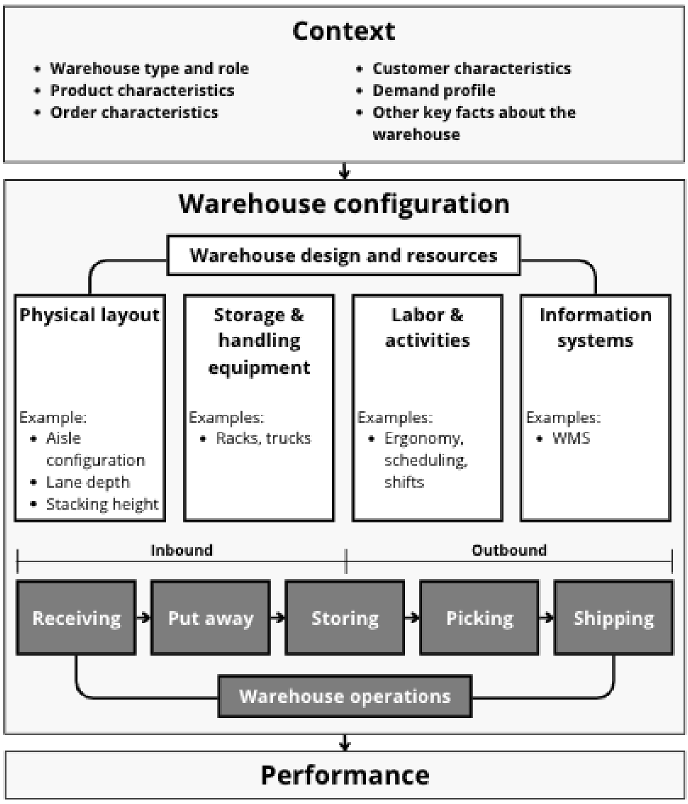


Figure 3.1: The adapted version of a contingency framework initially presented by Kembro and Norrman (2021).

Further describing contextual factors, they are also called situation attributes and can relate to either the company's internal or external environment (Kembro & Norrman 2021). Different types of contextual factors are discussed in research. Rouwenhorst et al. (2000) and Bartholdi and Hackman (2019) bring up the role of the warehouse as a critical factor to consider when designing a warehouse, since it affects what criteria the warehouse needs to meet. This thesis investigates a pre-assembly warehouse, where one main performance criterion is storage capacity (Rouwenhorst et al. 2000). Other contextual factors presented by Onstein et al. (2018) are demand level, service level, product characteristics, logistics cost, labor and land, accessibility, and regional or national regulations. Product characteristics are mentioned also by Da Cunha Reis et al. (2017) as a factor influencing the decisions in warehouse design, together with supply chain design, financial factors, and operational factors. Kembro and Norrman (2021) further list, besides the already mentioned product characteristics, order characteristics, customer characteristics, demand profile, volume, and assortment as contextual factors to consider. In Table 3.1 below, a summary of the contextual factors discussed in research and relevant for this thesis is presented.

Table 3.1: Examples of contextual factors relevant for this thesis, based on research by Bartholdi and Hackman (2019), Da Cunha Reis et al. (2017), Kembro and Norrman (2021), Onstein et al. (2018) and Rouwenhorst et al. (2000).

Contextual factor	**Description and what data points to look at**	**Warehouse configuration element influenced**
Warehouse type and role	Refers to the type of warehouse and its role in the supply chain	Overall operations
Product characteristics	Refers to the the different types of SKUs, their size and variety	Space needed, and storing and handling equipment needed
Order characteristics	Refers to the number of orders, order lines per order, and SKUs per order	Picking strategy and picking method
Customer characteristics	Refers to the number and type of customer, and their requirements	Space needed, and storing and handling equipment needed
Demand profile	Refers to seasonality in demand and picking frequency	Storage allocation method, flexibility of the warehouse

The configuration elements influenced by each contextual factor is a summary of literature by Bartholdi and Hackman (2019), Da Cunha Reis et al. (2017), Kembro and Norrman (2021), Onstein et al. (2018) and Rouwenhorst et al. (2000). For instance, Rouwenhorst et al. (2000) state that product characteristics influence the need for handling and storing equipment, and Bartholdi and Hackman (2019) mention that order characteristics influence the picking method. Some wording have been changed to suit this thesis. For example, Rouwenhorst et al. (2000) use the word SKU characteristics for what in this thesis is named product characteristics.

3.2 Warehouse Design and Resources

3.2.1 Physical Layout

Three main aisle configurations have been identified while reviewing available literature. These are parallel aisles, cross-aisles, and the fishbone layout. Which configuration is suitable depends on whether saving space or time is the most important, relating to the warehouse type and role (Bartholdi & Hackman 2019). It is also affected by the shape of the warehouse (Kocaman et al. 2021; Tutam & White 2023). Below follows a presentation of each, and in Table 3.2, it is presented in what context which aisle configuration layout is suitable.

A parallel aisle warehouse is where aisles span from one side to another, all parallel to each other, and there are no possibilities to move between the aisles other than to walk in the same direction as the aisle span, meaning there are no "openings" in the lanes for one to cross the aisles perpendicularly (Bartholdi & Hackman 2019). Cross-aisled warehouses are made up of blocks of parallel aisles, with some cross-aisles in between. This layout shortens travel time but is more costly than regular parallel aisles since more floor space is needed to provide the same number of storage locations (Bartholdi & Hackman 2019). The fishbone layout refers to a warehouse with angled cross-aisles (Bartholdi & Hackman 2019). According to Gue and Meller (2009), this layout significantly reduces travel time. However, it requires more space and hence a larger warehouse, than the previously listed aisle configurations (Bartholdi & Hackman 2019). The fishbone layout seems to be particularly beneficial to unit load warehouses where only one item is picked during the same picking journey through the warehouse (Mowrey & Parikh 2014). No matter the aisle configuration, aisles that run in the same direction as the material flow generally reduce the distance, and thereby time, spent traveling between receiving and storage locations as well as between storage locations and shipping (Bartholdi & Hackman 2019).

Table 3.2: A summary of what aisle configuration is suitable in what context, inspired by Bartholdi and Hackman (2019), Gue and Meller (2009), and Mowrey and Parikh (2014).

Aisle configuration	**Suitable context**
Parallel aisles	Need to save space
Cross-aisles	Reducing travel time is more important than saving space, but saving space is also a goal
Fishbone layout	Reducing travel time is important and space is not a constraint

To save space, SKUs can be stored in deep lanes, be stacked, or be stored in racking systems. All these measures ensure that the same aisle can be shared by many storage locations (Bartholdi & Hackman 2019). They also directly decrease the required aisle space in the warehouse. Each space saving measure is discussed below, and in Table 3.3, a summary of what context each space saving measure is suitable in is presented. The suitability of each measure depends on the contextual factors warehouse type and role, product characteristics, and demand profile.

Storing SKUs in deep lanes means storing SKUs behind each other. This might require special racking equipment and trucks that can reach deeper, and the risk of double handling increases (Bartholdi & Hackman 2019). Double handling means that a SKU is put down and picked up again at another time, which is costly (Bartholdi & Hackman 2019). To avoid double handling, Bartholdi and Hackman (2019) state that it is common to store the same SKU throughout the same lane. However, they highlight that a side effect of storing the same SKU throughout the whole depth is a loss in space savings due to so-called honeycombing. Honeycombing happens in first-in-first-out (FIFO) warehouses where the front locations are not made available even when the SKUs from those locations are picked.

Stacking is when unit loads, usually pallets, are stored on top of each other. This works for non-fragile, light unit loads with even top surfaces (Bartholdi & Hackman 2019). However, for fragile, heavy unit loads with uneven top surfaces, it is not feasible to stack many loads on top of each other. This results in a lot of unutilized space above the low stack.

To make better use of available space, racking systems can be installed (Bartholdi & Hackman 2019). Some advantages of moving an item from the floor to a rack highlighted by Bartholdi and Hackman (2019) are reduced labor due to easier storing and retrieving of product, creation of additional storage locations, protection from product damage, and a safer work environment.

Another measure to save space is minimizing the total aisle space by configuring aisles of mixed width (Mowrey & Parikh 2014). Wider aisles can be used in areas with more activity, and narrower aisles can be used in areas with little activity. Mowrey and Parikh (2014) have concluded that mixed-width aisles are more convenient for a warehouse with many storage locations, low space cost, and/or many aisles, and less desirable for warehouses with lower labor costs and lower throughput.

Table 3.3: A summary of what space saving measure is suitable in what context, inspired by Bartholdi and Hackman (2019).

Space saving measure	**Suitable context**
Deep lanes	Need to save space, the number stored of the same SKU is at least as large as the lane is deep, and honeycombing is not a problem
Stacking	Need to save space, and SKUs are non-fragile and light
Racking	Need to save space, SKUs are fragile and/or heavy, and double handling and honeycombing should be avoided
Mixed-width aisles	Large warehouse with low space cost, and/or many aisles, and/or high throughput

3.2.2 Equipment

There are two main types of equipment. The first is storing equipment used for storing SKUs and the second is handling equipment used to move SKUs. Both types are means to reduce the need for labor and space resources (Bartholdi & Hackman 2019). Below is a presentation of the two, based on the theory by Bartholdi and Hackman (2019).

What storing equipment is suitable depends on the warehouse type and role and the product characteristics. The most commonly used storage equipment is racks which allow for storing SKUs high without stacking them. Single-deep racks can store one unit load in depth. Their main benefit is that any position can be reached easily, however, they require more aisle space. Double-deep racks can stack two or more unit loads in depth, which is efficient from a space saving perspective. However, performing put away and picking from deeper racks is more time-consuming, and requires special equipment. Push-back rack is a version of double-deep racks, which are accessed from one side, and the shelves can be drawn out to make all SKUs accessible. Flow rack is a deeper rack where put away is made from one side, and picking from the other side, and the products slide through the rack due to a slight tilt of the shelves. They are typically useful for frequently picked products. Flow rack systems result in no interference between put away and picking, and enable FIFO, however, an extra aisle is needed. Drive-in and drive-through racks are racking systems where trucks can drive into the rack to put away and pick the SKUs. In drive-in racks, SKUs are put away and picked from the same side of the rack, and in drive-through racks, SKUs are put away and picked from different sides of the rack. In Table 3.4, a summary of the context suitable for each racking system is presented.

Table 3.4: A summary of what storing equipment is suitable in what context, inspired by Bartholdi and Hackman (2019).

Storing equipment	**Suitable context**
Single-deep rack	Need to follow FIFO
Double-deep rack	Need to save space, and SKUs can follow LIFO
Push-back rack	Need to save space and have easier access than double-deep racks can provide, and SKUs can follow LIFO
Flow-through rack	Need to follow FIFO, need to save space, need to avoid interference between put away and picking, and SKUs are picked frequently
Drive-in rack	Need to save space, SKUs can follow LIFO, and slower put away and picking is not a problem
Drive-through rack	Need to follow FIFO, need to save space, and slower put away and picking is not a problem

The choice of handling equipment should consider the warehouse type and role, product characteristics, and demand profile, or more specifically, the unit load types, picking patterns, facility characteristics, and how skilled the workers are (Bartholdi & Hackman 2019). Further, it depends on the storage equipment, for example, special trucks are needed to pick in deep or high racks (Bartholdi & Hackman 2019). Some common truck variants are presented below, following what has been presented by Bartholdi and Hackman (2019).

Counterbalance trucks work well in most settings but require quite a lot of aisle space, about three to slightly over four and a half meters in width, and have a limited lifting height of about six meters. Reach trucks have extendable forks and require less aisle space than counterbalance trucks, about two to slightly over two and a half meters in width, and they reach higher, about nine meters. However, they are generally slower than counterbalance trucks. Furthermore, they often need outriggers which the racking system must be adapted to. Turret trucks do not turn in the aisles, but turn 90 degrees thanks to a turret. This allows them to drive in narrow aisles, with widths of about one and a half to slightly over two meters and they can lift high, about 13 meters. However, they require a very flat floor and a guidance divide which the racking system must accommodate. Turret trucks are fast when moving in the aisles, but hard to maneuver outside their designated aisles. A summary of in what context which truck is suitable is presented in Table 3.5.

Table 3.5: A summary of what handling equipment is suitable in what context, inspired by Bartholdi and Hackman (2019).

Handling equipment	**Suitable context**
Counterbalance truck	Trucks need to function well in different types of aisles, SKUs are not stored higher than six meters, and aisles are relatively wide
Reach truck	SKUs are stored higher than six meters, and aisles are narrow
Turret truck	SKUs are stored high, aisles are very narrow, and the floor is solid

3.2.3 Information Systems

The information system dedicated to managing warehouses is the WMS, and it is a key resource for making warehouses effective (ten Hompel & Schmidt 2007). Each warehouse and supply chain is unique and has its requirements on the WMS, so the system selection must be made accordingly. However, there are some common features of most WMS, presented by Bartholdi and Hackman (2019), ten Hompel and Schmidth (2007), and according to SAP (2024). The most basic feature of a WMS is to keep track of the SKUs and storage locations in the warehouse, but the WMS can also be used to manage the acceptance, receipt, and inspection of incoming goods, and enable an effective product allocation and shelf space utilization. To make effective product allocations and use space effectively, the WMS should hold information about the dimensions of storage locations, constraints such as what goods can not be stored together and max weight allowances on shelves, and suggest allocations that minimize travel. WMS typically also has functionalities to generate pick lists that facilitate the picking strategy, picking method, and routing method. Further, a WMS can also be used for analytics and performance measurement. Even though the possibilities of WMS systems are large, Bartholdi and Hackman (2019) state that most WMS are still not intelligent enough to optimize anything, and need operators to set the system rules.

3.2.4 Labor and Activities

Warehouses require labor to operate, either in the form of personnel hired by the company or contracted externally. How much labor is needed is determined by, amongst other factors, the operating hours of the warehouse and the amount of activities performed. Typical main activities in a warehouse include receiving, put away, picking, checking, packing, shipping, and sorting (Bartholdi & Hackman 2019). The downstream activities are usually more labor intensive, since the unit loads handled are generally smaller (Bartholdi & Hackman 2019). According to Bartholdi and Hackman (2019), a goal should be to maximize the number of handles per hour for every worker in the warehouse, to lower the labor costs.

3.3 Warehouse Operations

3.3.1 Receiving

The first step of warehouse operations is goods receipt, which is when goods arrive at the warehouse, are unloaded, and staged for put away (Bartholdi & Hackman 2019). It is common for SKUs to be quality-checked and registered in the information system in this step so that ownership can be transferred and inventory levels can be updated (Bartholdi & Hackman 2019). The incoming goods usually arrive in large unit loads, such as pallets, and therefore might need to be repacked before being transported to the next process, for instance, if they are stored in smaller unit loads inside the warehouse (Bartholdi & Hackman 2019).

3.3.2 Put Away and Storage

Put away and storage refers to when received SKUs are transported to, and put in, their storage location (Klodawski et al. 2017). How SKUs are allocated highly impacts the utilization of warehouse space and time (Kofler et al. 2011), which essentially dictates the efficiency and cost-effectiveness of the warehouse (Bartholdi & Hackman 2019; Bindi et al. 2009; Zapata-Cortes et al. 2021). What storage allocation method is suitable depends on the product characteristics, customer characteristics, and demand profile of the warehouse. Below, some common storage allocation methods and their advantages and disadvantages are discussed. What method is suitable in what context is summarized in Table 3.6.

Dedicated storage is when each SKU has a dedicated storage location (Bartholdi & Hackman 2019; Kofler et al. 2011). A benefit of dedicated storage is that the workers can learn the location of each SKU, and the disadvantage is that the space utilization is low since once a SKU is picked, the position stays empty until the next replenishment cycle (Bartholdi & Hackman 2019; Bindi et al. 2009). Therefore, this storage allocation method is suitable when labor efficiency is more important than saving space, for example in areas where smaller and more frequently picked products are stored (Bartholdi & Hackman 2019). Another form of dedicated storage is full turnover storage, which is when storage locations are dedicated based on the SKUs picking frequency. This means that the SKUs are ranked based on how frequently they are picked, and the location with the shortest average travel and retrieval cost is dedicated to the most frequently picked SKU, which saves time (Chan & Chan 2011; Guo et al. 2016; Kofler et al. 2011; Petersen & Aase 2004).

The opposite of dedicated storage is random storage, which is when a storage location can be filled with any SKU as soon as it becomes empty (Bartholdi & Hackman 2019; Kofler et al. 2011). The benefits of random storage are many. For instance, it is relatively simple to implement and administrate, and it reduces congestion risk (Kofler et al. 2011; Petersen & Aase 2004). Furthermore, it enables high space utilization since an empty spot can be filled right away with any SKU, which is called the space-sharing effect (Bartholdi & Hackman 2019; Chan & Chan 2011). However, when the same SKUs can be located in different locations, it is more complicated for the pickers to know where to go which decreases efficiency (Bartholdi & Hackman 2019). Also, the distance traveled is generally longer compared to other methods (Kofler et al. 2011). Bartholdi and Hackman (2019) state that it is more common to use random storage allocation in zones where pallets are stored since such zones have more to benefit from effective space utilization. Closest storage is a form of random storage but with shorter travel distances and is when incoming SKUs are allocated to the first empty location closest to the inbound area (Bindi et al. 2009).

Affinity storage is when SKUs often ordered together are placed together (Chan & Chan 2011; Petersen & Aase 2004). This method can decrease the number of travels and is effective if the pick list sequences do not change much (Chan & Chan 2011).

Class based storage (CBS) is when the SKUs are divided into classes based on their picking frequency, and storage locations are grouped into zones (Ang & Lim 2019; Guo et al. 2016). The most frequently picked class is placed in the best zone, and within that zone, the SKUs are placed randomly (Ang & Lim 2019; Guo et al. 2016). CBS can be applied within aisle, where SKUs within the same aisle belong to the same zone, or across aisle, where each zone is located over several aisles (Chan & Chan 2011; Petersen & Aase 2004; van Gils et al 2018). CBS can also be applied both vertically and horizontally, where the first means putting the most frequently picked SKUs in the lowest shelves of the rack and the second is putting them in storage locations that minimize the travel distance. The first one decreases retrieval time, and the second decreases travel time (Chan & Chan 2011).

CBS has a lot of advantages and makes the best out of random storage and full turnover storage (Petersen & Aase 2004), thereby it is suitable when a warehouse needs to prioritize both saving space and time. CBS is also easier to implement and administrate than dedicated storage (Chan & Chan 2011; Rao & Adil 2014). Furthermore, the optimal number of classes in CBS is debated on, and Chan and Chan (2011) state that it depends on other elements of the warehouse operations, design, and resources. The more classes a CBS has, the more it resembles a full turnover storage (Petersen & Aase 2004).

According to Petersen and Aase (2004), the savings in travel time from applying full turnover storage or CBS increase with skewness in the picking frequency curve and with short pick lists. This is, the authors explain, because if the picking frequency curve is skewed, there are a few SKUs that stand for a majority of picks, and there is a lot to gain from placing these in prime locations. If the pick list is short, the probability of getting picks only in the A zone is higher. With long pick lists, the probability that a SKU on the list is located far away in the warehouse increases, and then long travels must be made anyhow. If the picking frequency curve is flat, meaning SKUs are demanded equally often, the probability is larger that a SKU on the pick list is located far away in the warehouse, and a storage allocation method based on picking frequency does not perform much better than a random storage allocation. Chan and Chan (2011) warn that there is a risk of building congestion when popular SKUs are placed together in full turnover or CBS.

Kofler et al. (2011) and Scheffler et al. (2021) say that, even though methods based on picking frequency can be effective for minimizing travel time, it can be difficult to assign SKUs to the theoretically most cost-effective places in practice. There can be other technical limits that must be accounted for, for example, the equipment, number of picking locations, work ergonomics, and so on. Due to this, Chan and Chan (2011) say that it can be beneficial to base a classification on more than one attribute, for example, supplier, customer, seasonality, dimensions of SKU, perishability, unit cost or value, and fragility.

Table 3.6: A summary of what storage allocation method is suitable in what context, inspired by Bartholdi and Hackman (2019), Bindi et al. (2009), Chan and Chan (2011), Guo et al. (2016), Kofler et al. (2011), Petersen and Aase (2004), Rao and Adil (2014), Scheffler et al. (2021), van Kampen et al. (2012), and van Gils et al. (2018).

Storage allocation method	**Suitable context**
Dedicated storage	Storing small and frequently picked SKUs, and labor efficiency is highly valued
Full turnover storage	Saving travel time is important, the picking frequency curve is skewed, and pick lists are short
Random storage	Saving space is more important than reducing travel time
Closest storage	Saving space and reducing travel time is equally important
Affinity storage	Reducing travel time is more important than saving space, certain SKUs are frequently picked together, and pick list sequences rarely change
CBS	Saving space and reducing travel time are both important, the picking frequency curve is skewed, and pick lists are short
Storage based on other SKU attributes than picking frequency	Being able to allocate SKUs based on other attributes than picking frequency is important to enable special handling, to save space or to reduce travel time

3.3.3 Picking

There are two types of picking strategies. Serial picking is when one order is picked by one picker at a time, and parallel picking is when one order is picked by multiple pickers at a time (Bartholdi & Hackman 2019). Generally, picking serially requires more time to complete an order, but picking in parallel requires coordination and consolidation of the work of all pickers (Bartholdi & Hackman 2019). In Table 3.7, a summary of what picking strategy is suitable in what context is presented.

Table 3.7: A summary of what picking strategy is suitable in what context, inspired by Bartholdi and Hackman (2019).

Picking strategy	**Suitable context**
Serial picking	Coordination and consolidation of work between multiple pickers should be avoided, it is not possible for multiple pickers to pick the same order, or picking speed is not a major priority
Parallel picking	Picking speed is important, and orders can be consolidated after picking

The picking strategy, together with the order characteristics and demand profile, affects the choice of picking method. A suitable picking method can increase efficiency and reduce travel time in picking, which are both important factors for reducing costs in warehouses (Bartholdi & Hackman 2019; Gildebrand & Josefsson 2014). Below, four main types of picking methods are presented, and in Table 3.8 follows a summary of what context is suitable for what picking method.

Single-order picking is when the pickers pick all SKUs for one order during one tour of the warehouse before they move on to do the same for the next order. This method is easily implemented, maintains order integrity, and no coordination or consolidation is required between the pickers (Bartholdi & Hackman 2019; Gu et al. 2010; Petersen & Aase 2004). The downside is that it can result in lots of traveling, and it is not possible to "speed pick" large quantities of the same SKU (Bartholdi & Hackman 2019; Gu et al. 2010; Manzini 2012; Peterson & Aase 2004).

Batch picking means that the pickers are each assigned a group of different orders, to be picked simultaneously during one tour of the warehouse (Gu et al. 2010; Petersen & Aase 2004). According to Peterson and Aase (2004), it reduces travel time. The downsides are lost order integrity, risk for errors or inefficient sorting, and more planning is required than in single-order picking (Bartholdi & Hackman 2019; Gu et al. 2010; Manzini 2012; Peterson & Aase 2004).

Zone picking is when the warehouse is divided into picking zones, and the pickers pick SKUs only from the zone they are assigned to (Gu et al. 2010). According to Bartholdi and Hackman (2019), Gu et al. (2010), Manzini (2012), and Peterson and Aase (2004), this method reduces travel time and congestion risk, increases accountability for pickers, and possibly also increases picking efficiency since pickers become familiar with their zones. They highlight that zone picking is suitable when the number of SKUs is large, the demand is high, and the order size is small to moderate.

Wave picking means that the pickers in each zone get assigned a certain amount of orders to pick, and are asked to complete the picks in their respective zone during a set time, a "wave" (Gu et al. 2010). A wave can for example be a shift (Gu et al. 2010). This ensures that there are not a lot of half-finished orders in the sorting or shipping area, due to differences in picking efficiency between zones. According to Bartholdi and Hackman (2019), Gu et al. (2010), Manzini (2012), and Peterson and Aase (2004), this method leads to the same benefits as zone picking and additionally allows "speed picking" large quantities of the same SKU. It is suitable when the number of SKUs is large, the demand is heavy, and the order size is moderate to large.

Table 3.8: A summary of what picking method is suitable in what context, inspired by Bartholdi & Hackman (2019), Gu et al. (2010), Manzini (2012), and Peterson & Aase (2004).

Picking method	**Suitable context**
Single-order picking	Few orders and large order size
Batch picking	Many orders and small order size
Zone picking	Many orders, small to moderate order size, and the number of SKUs in the storage area is large
Wave picking	Very large amount of orders, moderate to large order size, and the number of SKUs in the storage area is large

Another configuration element within picking is routing, which refers to the sequence in which orders are picked, and what path is used to travel between the sequenced locations (Petersen 1997). Routing influences the travel times (Bartholdi & Hackman 2019). According to Bartholdi and Hackman (2019) and van Gils et al. (2018), the decision of whether it is worth having a routing method depends on the picking strategy and picking method, the abilities of the WMS, the competence of the workers, and the order characteristic order lines per order, which dictates the pick list length. If the pick lists are very short, shorter than four pick lines, or so long that they require picks from storage locations all over the warehouse, the benefits of having a routing method are small. Furthermore, the routing method needs to interact well with the picking method and storage allocation method (Bartholdi & Hackman 2019; van Gils et al. 2018). For example, if batch picking is applied, fewer locations are visited, and the need for a complex routing strategy decreases. Four common routing methods, presented by Bindi et al. (2009) and Chan and Chan (2011), are described below, and the context in which each is suitable is presented in Table 3.9.

Transversal routing is when the picker travels the entire length of each aisle that contains a pick location. With this method, the width of aisles can be reduced since aisles are only traveled in one direction, but it can lead to unnecessary travel. It works better when pick lists are long. Return routing is when the picker enters and exits the aisle from the same side, and enters each aisle that contains a pick location. This method can be useful to minimize travel distances if frequently picked SKUs are placed close to where pickers enter the aisle. Midpoint routing is when the picker enters and exits the aisle from the same side, but picks only in locations that are before the midpoint of the aisle. The procedure begins with picking in all locations from one side of the midpoint and then picking from the other side of the aisle. This method requires that the aisles can be entered from both sides, and it works better when pick lists are relatively short. Largest gap is similar to midpoint; the picker enters and exits the aisle from the same side, does this for all aisles, and then does the same procedure but starting from the other side. The difference is that the picker might cross the midpoint, if it is more time-saving to do so than to pick later from the other side. This method saves time but is more complex compared to midpoint, and therefore requires a WMS to guide the worker on what sequence to pick in. It works better when pick lists are relatively short.

Table 3.9: A summary of what routing method is suitable in what context, inspired by Bartholdi and Hackman (2019), Bindi et al. (2009), Chan and Chan (2011), and van Gils et al. (2018).

Routing method	**Suitable context**
Transversal routing	Long pick lists, and/or narrow aisles
Return routing	The storage allocation method is based on picking frequency
Midpoint routing	Relatively short pick lists and the WMS can support the method
Largest gap	Relatively short pick lists and the WMS can support the method (even more complex than midpoint)
No routing method at all	Very short pick lists, pick lists contain picks all over the warehouse, and/or the WMS can not support a routing method

3.3.4 Shipping

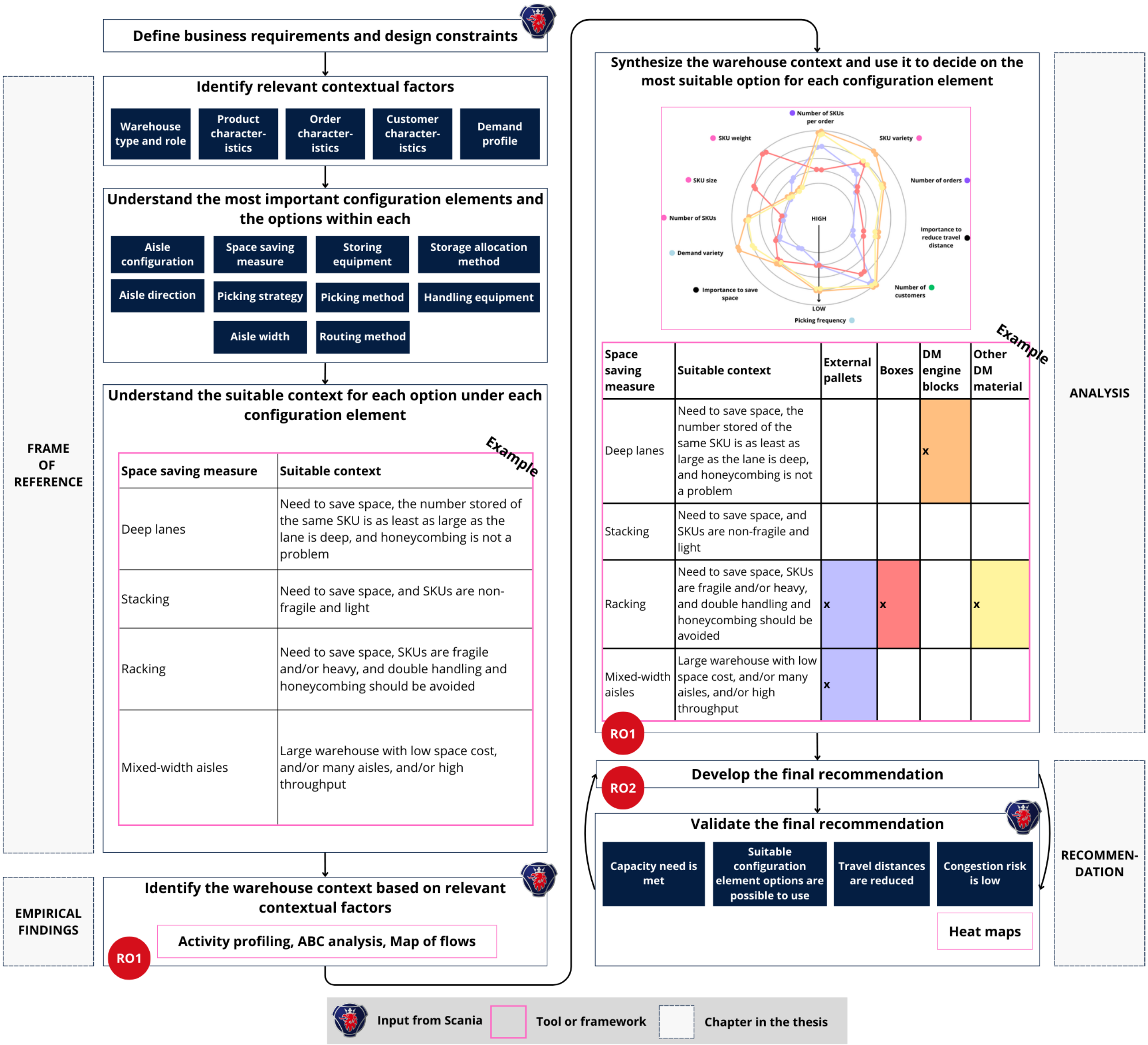
Shipping is the activity taking place after picking, and it concerns transporting the picked orders to the customer. Shipping typically requires less labor than picking, since larger quantities are handled than in picking (Bartholdi & Hackman 2019). In a pre-assembly warehouse, shipping refers to the transport between the warehouse and the assembly facility. As with all other operations, shipping can be based on different strategies and utilize different transportation modes.

3.4 Analytical Framework

Several methods and approaches for configuring warehouses are highlighted in literature. In this thesis, the ones presented by Baker and Canessa (2009), Rupasighe and Dissanayake (2018), and Rushton et al. (2014) are used as inspiration for developing an analytical framework, which can be seen in Figure 3.2.

All three research papers agree that designing a warehouse should be done step by step, however in an iterative manner, and they all suggest beginning with defining business requirements and design constraints. Thereafter, they include steps related to collecting data, and, after that, they suggest moving on to designing and developing the warehouse design, corresponding to this thesis' step of designing and developing the artefact. Finally, they mention validating and evaluating the warehouse configuration, which represents the demonstration and evaluation step of this research.

For validating the warehouse configuration, several criteria can be considered, depending on the goals of the configuration. In this thesis, four criteria have been deemed relevant. First of all, the configuration should meet the capacity need. Second, the most suitable configuration element options based on the warehouse context should be possible to use, since this is expected to improve the warehouse performance (Faber et al. 2018; Kembro & Norrman 2021). Third and fourth, it is also important that the configuration aims for short travel distances and avoids congestion (Bartholdi & Hackman 2019; Bindi et al. 2009; Chao-Hsien Pan & Shih 2008; Zapata-Cortes et al. 2021). To identify potential congestion issues, heat mapping is a helpful tool that visualizes the warehouse activity. Heat maps are developed by shading all storage locations in the warehouse based on their activity, lighter for less activity and darker for more activity (Bartholdi & Hackman 2019).



Space saving measure	Suitable context
Deep lanes	Need to save space, the number stored of the same SKU is as least as large as the lane is deep, and honeycombing is not a problem
Stacking	Need to save space, and SKUs are non-fragile and light
Racking	Need to save space, SKUs are fragile and/or heavy, and double handling and honeycombing should be avoided
Mixed-width aisles	Large warehouse with low space cost, and/or many aisles, and/or high throughput

Space saving measure	Suitable context	External pallets	Boxes	DM engine blocks	Other DM material
Deep lanes	Need to save space, the number stored of the same SKU is as least as large as the lane is deep, and honeycombing is not a problem			x	
Stacking	Need to save space, and SKUs are non-fragile and light				
Racking	Need to save space, SKUs are fragile and/or heavy, and double handling and honeycombing should be avoided	x	x		x
Mixed-width aisles	Large warehouse with low space cost, and/or many aisles, and/or high throughput	x			

Figure 3.2: The analytical framework used in the thesis.

The analytical framework displays in which order the research objectives are considered, and which tools are used in the analysis. The key is to understand that the warehouse context constitutes the core of the recommendation and that it therefore is necessary to first identify contextual factors for warehouses and how they affect different warehouse configuration elements. In this case, the relevant contextual factors are warehouse type and role, product characteristics, order characteristics, customer characteristics, and demand profile. For these contextual factors, the relevant configuration elements are aisle configuration, aisle direction, aisle width, space saving measures, storing equipment, handling equipment, storage allocation policy, picking strategy, picking method, and routing method. Each of these configuration elements has several options that are more or less suitable depending on the warehouse context, which has been presented in tables throughout this chapter. This knowledge base is brought into the analysis and matched with the context identified in the empirical findings. This matching leads to decisions on which option is best for each configuration element. The recommendation is then finalized by gathering all insights in the analysis and validating the recommendation on the four validation criteria. If the recommendation does not meet all criteria, some configuration elements are revisited and decisions on these are changed. This iterative approach is continued until the validation criteria are met.

Chapter 4

Empirical Findings

This chapter presents the findings from interviews, observations, and secondary data. The chapter begins by diving deeper into each relevant contextual factor. Thereafter, the warehouse design, resources, and operations are presented. All information represents year 20YY when the DL engine has been phased out if nothing else is stated. The notation "XX" replaces confidential data.

4.1 Contextual Factors

4.1.1 Warehouse Type and Role

The warehouse's main role is to provide the engine assembly with engine components on time so the assembly lines can run according to their production schedule. To do this, the warehouse acts as a decoupling point between suppliers and the assembly. Enough stock is kept to ensure that the engine assembly demand can be satisfied even if supply chain disruptions occur. The delivery reliability varies amongst suppliers, and since the suppliers are spread across the globe, the lead times also vary. In addition, the assembly sometimes closes for a couple of hours, a shift, or even days, for example if there is an issue in production or the end customer demand is lower than what the production schedule was planned for. This means the warehouse must be flexible enough to manage a stop in outbound volume while the inbound volume remains. This emphasizes the need for high storage capacity in the warehouse.

During interviews, the consensus is that the current warehouse has severe capacity issues, and the loads that do not fit in the pre-assembly warehouse are stored in an external warehouse. Based on a fill rate of 85%, the capacity need by the time of the DL phase-out is 23450 storage locations, of which 11252 are pallet locations. This would not fit in the current warehouse if no configuration changes were made. One goal of the reconfiguration is therefore to use the space inside the warehouse more effectively, and hopefully eliminate the need for the external warehouse. Effective space utilization is especially important in areas where pallets are stored since they require a lot of space.

By the time of the reconfiguration, the assembly will consist of two main assembly lines, DW and V8, which assemble three engine types: DW, V8, and PS. The assembly lines have different capacities and run after different production schedules. The set production schedule is communicated to the warehouse approximately three production weeks in advance, but minor changes can be made after that as well. The warehouse has a lead time promise to deliver SKUs within two hours from when they have been ordered by the engine assembly, which means that picking and outbound operations are prioritized over inbound operations.

Furthermore, Scania is committed to being the leader in sustainable transport. They focus on continuous improvement and have a demand-driven value creation, which for them translates into the following principles: make flows as efficient as possible, reduce waste, deliver the right amounts at the right time, and do not start working if there is no demand or need for what you deliver. When doing this, the following priority order rules: (1) safety - always make sure the processes are safe, healthy, and environmentally sound; (2) quality - only produce and deliver products, services, and solutions that have the right quality; (3) delivery - agree on what, when, and in which quantity delivery to customer happens, and; (4) cost - strive to reduce costs where possible to remain profitable. The company's core values are customer first, respect, team spirit, responsibility, and elimination of waste. These priorities and values also reflect the warehouse's role, in the way that the warehouse should always put safety first, and thereafter quality, delivery, and then cost-effectiveness.

A last note about the warehouse type is that it applies FIFO, which is a must also in the future. This strategy affects the warehouse configuration since certain elements are better suited for FIFO than others. During an interview, lane depth was mentioned as a critical factor to consider when having a FIFO strategy in a warehouse.

4.1.2 Product Characteristics

It is decided that the reconfiguration should account for a SKU range made up of all current DW, V8, and PS SKUs plus already planned SKU introductions until 20YY. All SKUs should be held in stock at all times, and the stock levels are determined by the coverage time targets, which are XX days for pallets and XX days for boxes on average. Active SKUs, meaning SKUs that can be ordered by customers, with zero predicted demand in the upcoming month only occupy one storage location each. Scania also builds up safety buffer stock for certain SKUs, if they have a problem with a supplier supplying that SKU. The warehouse does not need to be configured to store this extra stock. This means that the warehouse needs to handle about 3949 unique SKUs in year 20YY, whereof 1519 are stored on pallets, 2430 are stored on boxes and the few rest are stored on unknown unit loads.

The SKUs are stored in groups based on the unit load they are stored as, what type of unit load they are picked as, and what type of product they are. The main groups are external pallets, boxes, DM material, carton picked SKUs and piece picked SKUs. The DM material is strategic SKUs stored on pallets, produced in other Scania facilities in Södertälje, and delivered by an internal supplier. They can be further divided into DM engine blocks and other DM material.

Carton picked SKUs are stored on pallets, while piece picked SKUs are stored on either pallets or boxes. Each of these groups of SKUs requires different storing equipment, handling equipment, and different ergonomics and safety rules to be considered. In Table 4.1 below, a summary of the number of SKUs and number of storage locations needed for each group is presented. Note that the carton picked SKUs and piece picked SKUs need to be assigned a place in the warehouse in the new configuration. Therefore, some findings for these groups are relevant to present in this chapter. However, decided with Scania, a detailed configuration for these SKUs does not have to be delivered, mainly due to a lack of sufficient and accurate data.

Table 4.1: An overview of the different groups and their capacity need in year 20YY.

Group	**Number of SKUs**	**Number of storage locations occupied**	**Number of storage locations needed based on 85% fill rate**
External pallets	1501	9477	11150
Boxes	2433	9287	10926
DM engine blocks	3	37	44
Other DM material	28	49	58
Carton picked SKUs	186	186	186
Piece picked SKUs	1080	1080	1080

The exact unit loads to be used in year 20YY are not settled since Scania plans to update the packaging pool. A drastic change in SKU dimensions could theoretically affect all aspects of the warehouse configuration. However, the packaging plan from March 2024 indicates that the new unit loads will have the same width and length as today. With this in mind, it is decided with Scania that the warehouse configuration recommendation in this thesis should use the dimensions of the 2024 unit loads. The exception is that a box called B4 is excluded since its phase-out has already begun and it should be gone by the time of the warehouse reconfiguration.

When it comes to base measures, there are two sizes of pallets used, EUR 1 and EUR 6, which are called full and half pallets. They come as both plastic and wood pallets and of varying heights, depending on the number of collars. The plastic boxes come in four sizes. The warehouse also occasionally handles some special unit loads, which come in varying dimensions, but they can be classified as either pallets or boxes. All SKU sizes are presented in Table 4.2. The numbers used for naming is Scania specific.

Table 4.2: The different SKU sizes in the warehouse.

Type	**Name**	**Length (mm)**	**Width (mm)**	**Height (mm)**
Full pallet	11	1220	820	360
Full pallet	12	1220	820	560
Full pallet	13	1220	820	760
Full pallet	14	1220	820	960
Full pallet	15	1220	820	1160
Half pallet	21	820	620	335
Half pallet	22	820	620	535
Half pallet	23	820	620	735
Half pallet	24	820	620	935
Full pallet	32	1220	820	570
Full pallet	33	1220	820	770
Full pallet	34	1220	820	920
Half pallet	71	820	620	380
Half pallet	72	820	620	580
Half pallet	73	820	620	780
Box	B1	297	198	147
Box	B2	396	297	147
Box	B3	594	396	147
Box	B4	600	400	220
Special pallet	50	NA	NA	NA
Special pallet	99	NA	NA	NA
Special pallet	J1	NA	NA	NA
Special pallet	J2	NA	NA	NA
Special pallet	MB	NA	NA	NA
Special pallet	N2	NA	NA	NA
Special pallet	Y3	NA	NA	NA
Special box	SB	NA	NA	NA

For simplicity, the special unit loads are not included in any compilations of data shown, discussed, or analyzed in this thesis. In calculations for year 20YY, the B4 volumes are distributed evenly amongst the three other box types. In Figure 4.1 below, a visualization of the distribution of storage locations between the main unit loads, pallets and boxes, can be seen. The pallet SKUs are distributed amongst 7196 full pallets and 4056 half pallets.

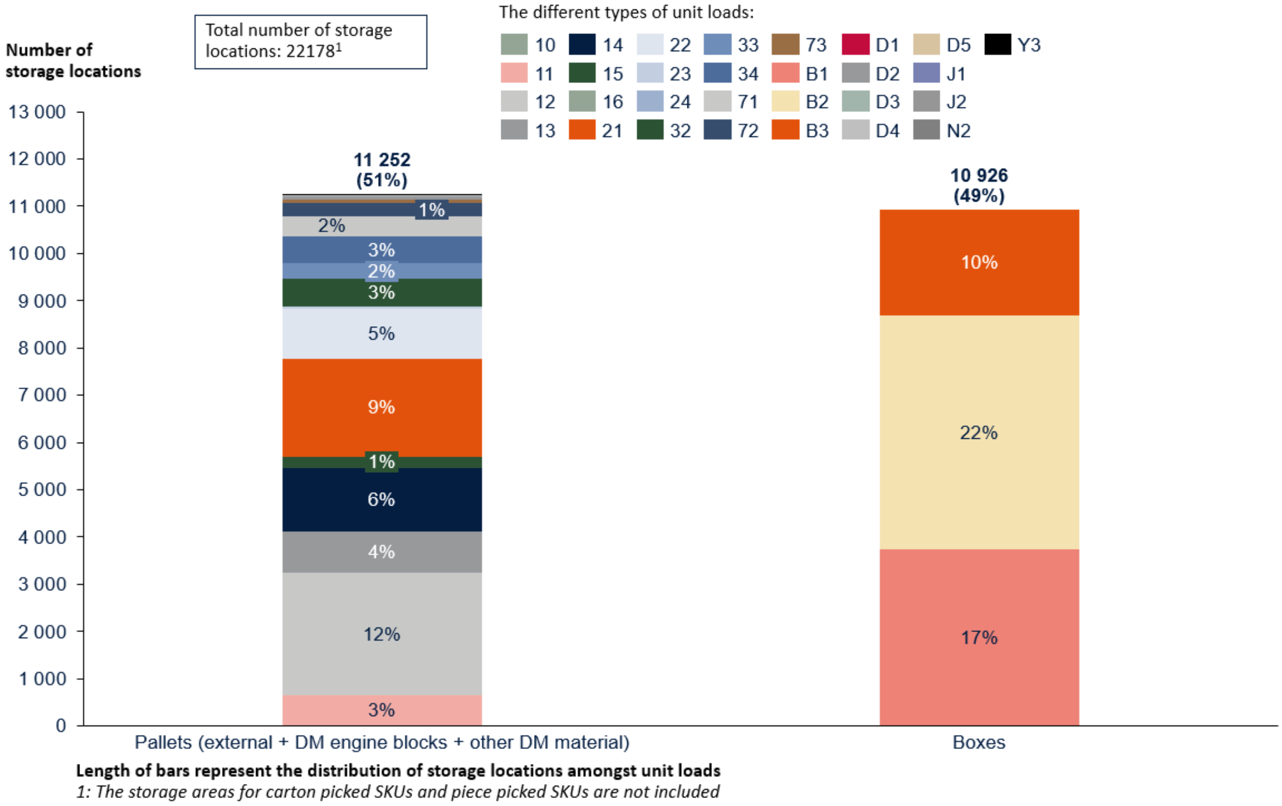


Figure 4.1: Distribution of the two main unit loads inside the warehouse. Based on data from March 2024 and scaled linearly towards the future expected production rate.

To finalize the product characteristics contextual factor, it is worth mentioning that SKUs vary in unit cost, ranging from XX SEK per component to 1000XX SEK per component. Scania currently tries to store the most valuable SKUs on floor level, since the economic damage of dropping them from higher shelves is major. There are no particularly fragile, temperature-sensitive, or dangerous goods SKUs. Worth mentioning is however that Scania currently tries to store all heavy SKUs (weight above 500 kg) on the floor, and generally, stores heavy SKUs on low levels. This is due to the severe safety risk of dropping a heavy SKU from a high level.

4.1.3 Order Characteristics

Before looking into the number of orders, order lines per order, and SKUs per order for the different groups, an explanation of how orders arrive at the warehouse is provided. The engine assembly places so-called delivery requests to the warehouse, where each delivery request is for a single item. The requests are triggered automatically for some items and manually for some. In the warehouse, these delivery requests are handled differently depending on the group. For the group external pallets, orders are created by manually gathering a couple of delivery requests and putting them together. Each delivery request becomes an order line on that order. For the boxes, orders are created by letting the information system gather delivery requests during a set time frame and create multiple orders at the end of that time frame, where each delivery request becomes an order line. For both external pallets and boxes, the orders function as pick lists, and each order line becomes a pick line. On average, the external pallets are picked three at a time, based on stackability limits of 12 levels, where one level is either a pallet base or a collar. The average number of order lines per order, and thereby the pick list length, is therefore three for external pallets. This is also the average number of SKUs per order since all external pallets are picked as full unit loads. In total, the engine assembly requests around 1669 single external pallets daily, which results in approximately 556 orders. For boxes, the number of order lines per order is on average 15, which also represents the number of SKUs per order. In total, the engine assembly requests around 1367 boxes daily, which results in approximately 91 orders.

For each engine assembled, one DM engine block is needed. XX engine blocks are requested each day, which results in XX orders since there is one order line per order for V8 but two order lines per order for DW for this group. For other DM material, the demand varies, but on average it is expected that 168 SKUs of this group will be requested daily. For this group, delivery requests are not consolidated, which results in all orders being one order line long. Since each order line represents a single pallet, the SKUs per order are also one.

Regarding carton picked SKUs and piece picked SKUs, their order characteristics need to be understood because they dictate their placement in the warehouse, which is part of the recommendation. The carton picked SKUs are stored together in groups of 30 or 60 on half pallets, but are requested as single cartons. On average, 993 cartons are requested each day. These requests are gathered by the information system, and orders of around 25 order lines are created. Each order line represents a carton. This means that the average number of orders per day for this storage area is 40, and the SKUs per order is:

$$0.5 \times \frac{25}{30} + 0.5 \times \frac{25}{60} = 0.63$$

For the piece picked SKUs, the data available is severely limited, why no accurate number of orders can be presented. However, the number of orders per unique engine is a maximum one, meaning that the maximum number of orders to this storage area per day is the number of engines assembled per day, which in 20YY is estimated to be around XX on average. Each order might include requests for one to over 100 items, which represents one to over 100 order lines. In the piece storage area, the items are stored on pallets and in boxes, and the number of items per SKU varies a lot. Therefore, the number of SKUs per order can not be stated either. In Table 4.3, a summary of the order characteristics per group is presented.

Table 4.3: An overview of the order characteristics for the different groups. The numbers represent the daily demand on average.

Group	**Number of orders**	**Number of order lines per order**	**Number of SKUs per order**
External pallets	556	3	3
Boxes	91	15	15
DM engine blocks	XX	2 for DW, 1 for V8	1
Other DM material	168	1	1
Carton picked SKUs	40	25	0.63
Piece picked SKUs	Max. XX	-	-

4.1.4 Customer Characteristics

The main customer for the warehouse is the engine assembly, which assembles Scania's three main engines DW, V8, and PS. They are considered the actual customers of the warehouse. The DW and V8 have their own assembly lines as previously mentioned, while PS is pre-assembled on either the DW or V8 line and then transported and finalized in another building in Södertälje. Some components stored in the warehouse can be ordered only by one customer, and some can be ordered by all. Due to the Scania philosophy of modular systems, many variants of the engines are assembled every day, and each variant requests a unique set of components from the warehouse.

The most important finding in customer characteristics is that each customer requires its orders to be delivered in a certain way, to a certain place, varying depending on what group the order is placed to. These requirements will remain the same in 20YY and are more thoroughly explained under the section warehouse design and resources further down in this chapter.

All customers order items from all groups inside the warehouse but in varying volumes. An important finding is that there are more than three main customers for the boxes. In fact, there are five. This is because the DW assembly line is split into two customers - DW1 and DW2 - and the V8 assembly line is split into two customers - V81 and V82. These different customers represent different addresses along the assembly lines. However, the data availability limits the separation of these in terms of storage locations. Therefore, DW1 and DW2 are merged into DW, and V81 and V82 are merged into V8 in Figure 4.2, which shows the number of storage locations per group and customer.

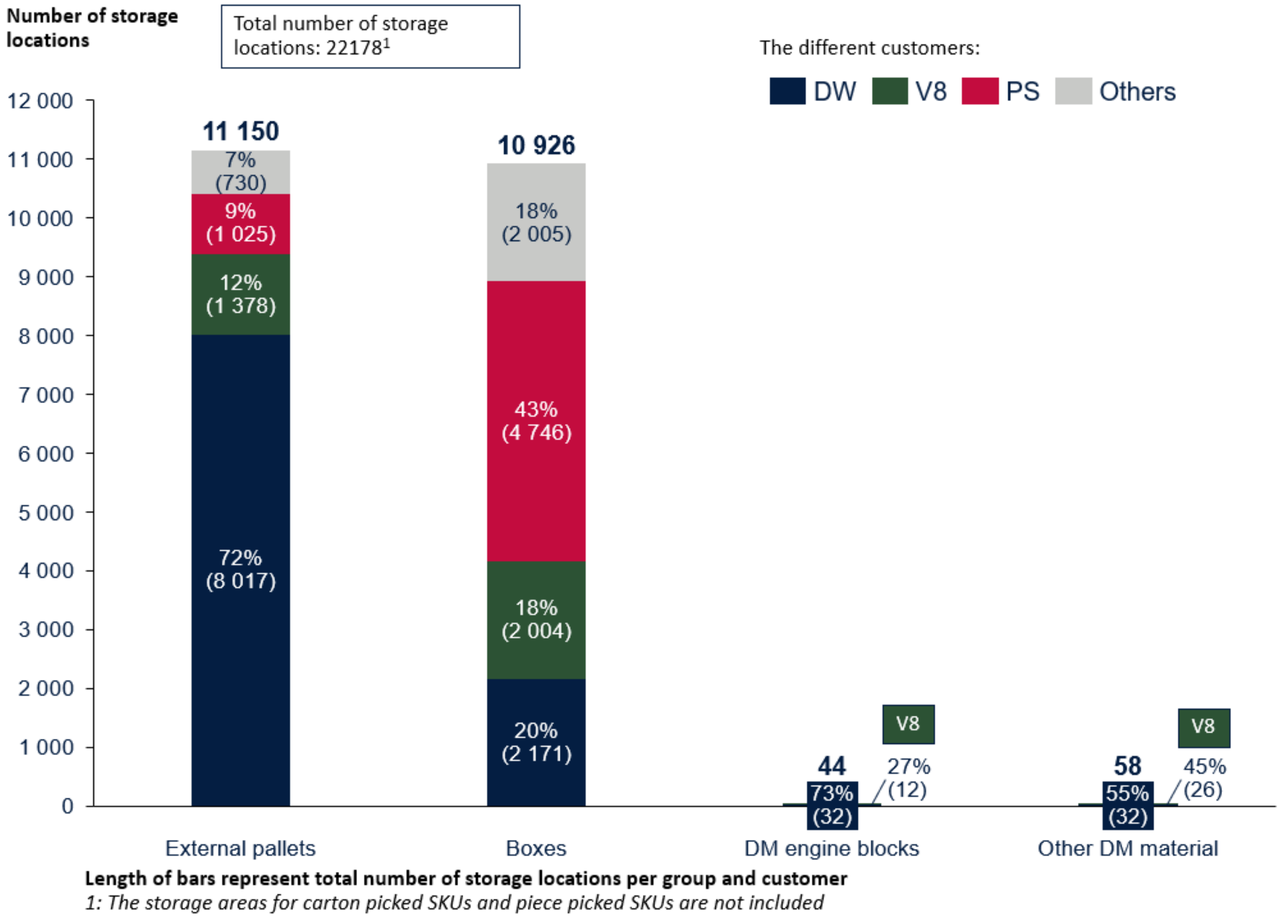


Figure 4.2: The number of storage locations per group and customer. "Others" represent internal customers, such as the painting station, quality assurance, and replenishment of storage areas from others.

4.1.5 Demand Profile

There is no significant seasonality in demand, however, the number of picks varies a lot between SKUs, based on picking data from November 2023 to January 2024. The top 20% of the SKUs stand for 77% of the total number of picks. This skewed picking frequency is presented in Figure 4.3 below.

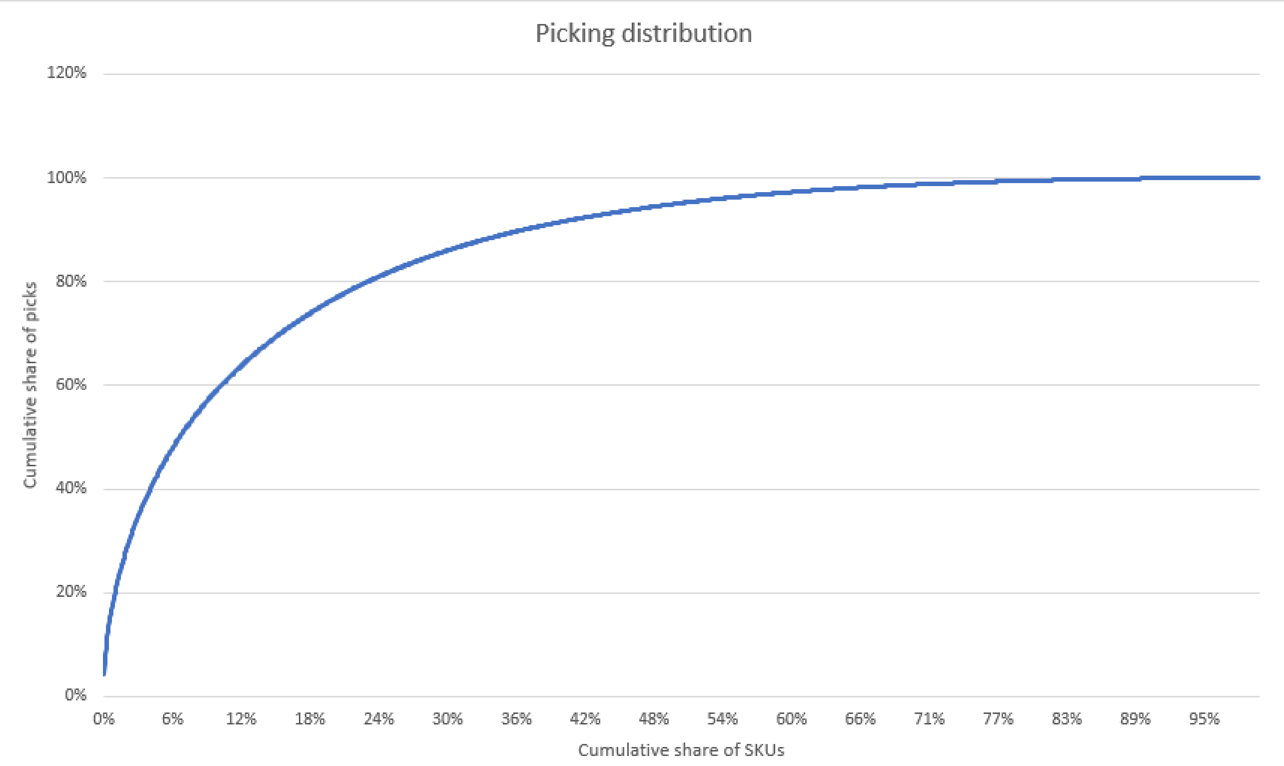


Figure 4.3: The picking distribution of all picks made in the warehouse from November 2023 to January 2023. This trend is believed to be representative of the situation by the time of the reconfiguration as well.

Diving deeper and looking into the different storage areas separately, it can be concluded that for external pallets, 20% of items stand for 70% of the picks. For boxes, 20% of SKUs stand for 75% of the picks. For other DM material, 20% of the items stand for 83% of the picks, whereas the top two SKUs stand for almost half of the total number of picks made. For DM engine blocks, there are only three SKUs, and they are on average picked XX, XX, and XX times per day respectively. To sum up, all groups seem to experience a skewed picking frequency curve. Note that for carton picked SKUs and piece picked SKUs, the lack of data makes a picking frequency analysis non-feasible. A summary of the picking frequency per group is presented in Table 4.4 below.

Table 4.4: A summary of the demand profile per group. The number of picks are average per day.

Group	**Number of picks**	**Skewed picking frequency curve?**
External pallets	1669	Yes, moderately skewed
Boxes	1367	Yes, moderately skewed
DM engine blocks	XX	Not relevant
Other DM material	168	Yes, skewed

When diving even deeper into the demand profile and looking into picks made for different customers per group, it turns out that the DW SKUs stand for the most picks in all groups. The picks per customer and group per day on average are presented in Figure 4.4 below.

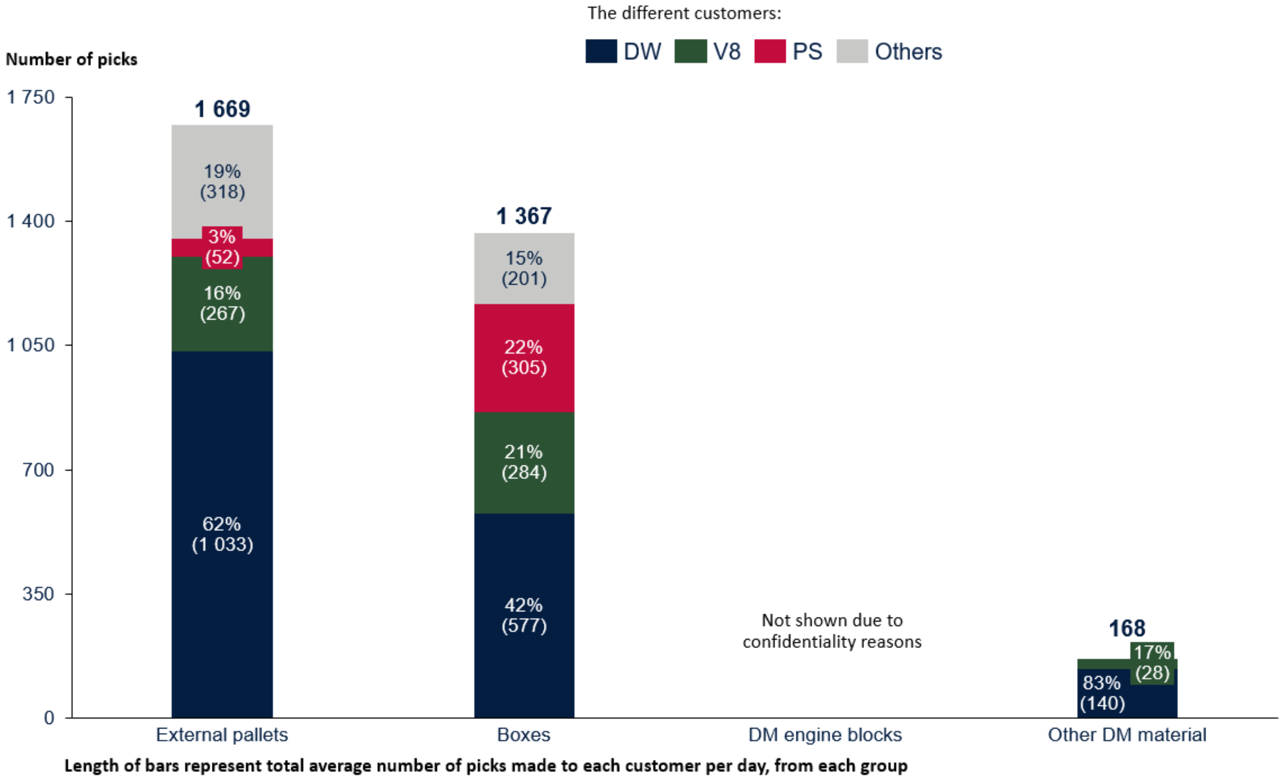


Figure 4.4: Number of picks per customer and group per day on average.

According to interviews and observations, the picks are made relatively evenly throughout the day, with a somewhat higher intensity in the morning shift than in the evening shift. The number of picks is also quite similar throughout the week, with a slight skew to the first days of the week. There is no available secondary data that suggests the opposite. Further, there is no available data to use for exploring affinity possibilities, and according to the interviews, the affinity possibilities are few.

4.2 Warehouse Design and Resources

4.2.1 Physical Layout

The overall physical layout of the warehouse is visualized in Figure 4.5. The building is rectangular, the north and south walls being 119 meters and the east and west sides being 74 meters. This gives a total warehouse area of 8806 square meters. The goods receiving area is located outside the north wall. All SKUs arrive there, and PS SKUs are also shipped from there. The other SKUs are delivered to the engine assembly, which is located on the other side of the west wall. There are three gates on the west wall named A, B, and C, three gates on the north wall named D, E, and F, and a pallet roll rack by the north wall named P. The pallet roll rack has four lanes where EUR pallets can be put. In the middle of the facility, there are two lanes with ten pillars each that run from the west to the north wall. The warehouse configuration does not have to consider these. In the northwest corner of the building, there is the mezzanine floor that limits the height of equipment that can be put there, and it has corner pillars where trucks can not drive. This needs to be considered in the warehouse configuration. The ceiling on the north wall is higher than the ceiling on the south wall, with the lowest point along the south wall, and the highest point about three-quarters into the building towards the north wall. Additionally, there are ventilation pipes, lamps, and other gear in the ceiling which limit the total available height. With this in mind, the available height ranges from six to ten and a half meters, with the majority of the warehouse being closer to ten and a half meters than six meters. A simplification is made by assuming that the available height is nine meters all over the warehouse.

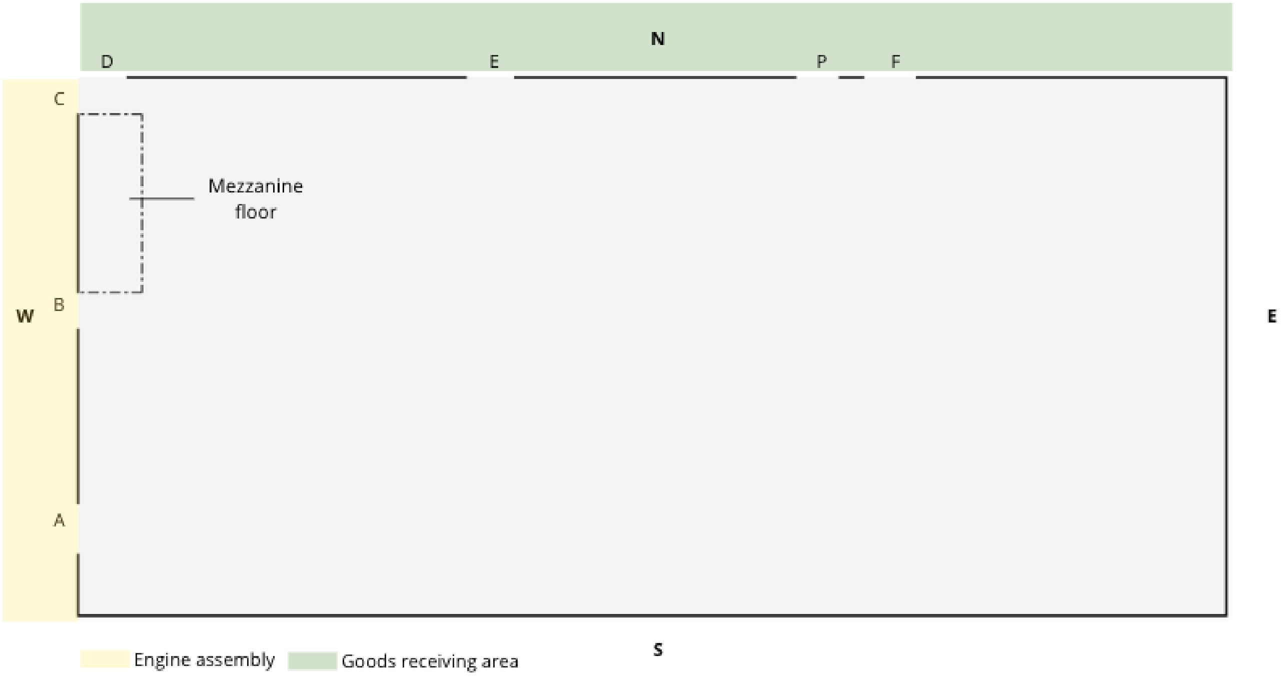


Figure 4.5: The facility layout, with the location of the goods receiving area and the engine assembly pointed out.

The carton picked SKUs and the piece picked SKUs should be their own storage areas in 20YY and remain configured similarly as to how they are today. This means allocating one rack, eleven and a half meters long, with three and a half meter wide aisles, for the carton picked SKUs, and four racks that are 19.5 meters long each, with three and a half meter wide aisles, for the piece picked SKUs. In the final recommendation, certain areas that are not used for storage must also fit, but it is out of scope to design the exact layout of them. Such areas are group meeting areas, truck parking areas, truck charging areas, sorting areas, andon areas, handover areas, working areas, and pedestrian aisles. These areas are hereafter referred to as other areas. In total, they require 1385 square meters. Additionally, 150 square meters inside the warehouse have been promised for operations outside of the warehouse scope. All of these areas limit the space available to use for storing SKUs, as well as moving goods, in the warehouse.

Moreover, the configuration must follow Scania's safety and ergonomics rules. A key rule relates to the width of aisles. A minimum aisle width exists to ensure safe and efficient warehouse operations that minimize the risk for damage of goods, people, the facility, equipment, and so on. The width of a transport aisle for one-way truck traffic must be the width of the widest truck plus zero point six meters, and at least two point two meters. If two-way truck traffic is desired, the aisle must be as wide as the widest truck plus zero point nine additional meters, and at least three and a half meters wide. Pedestrian aisles must always be separated from the vehicle traffic, and they must at least be zero point nine meters wide for one-way traffic and one point two meters wide for two-way traffic. Furthermore, based on interviews and observations, it is recommended to add more aisle space on top of the recommended dimensions to facilitate operations and decrease the risk of damage. For aisles where trucks have to turn for picking, about half a meter extra width is recommended.

4.2.2 Equipment

The handling equipment used in inbound operations and the storing equipment can be changed in the configuration recommendation. However, if the analysis does not indicate that a change of equipment is suitable, the equipment used in 2024 will be kept, and therefore it is useful to understand what it looks like today. Also, the equipment used to transport and present the SKUs to the customers must be the same in 20YY as in the current configuration. This requirement affects the picking and outbound operations.

In 2024, most pallets are stored in single-deep pallet racking systems, and a few frequently picked pallets are stored in flow racks. All pallet storage locations are designed to be able to store full pallets, but of varying heights. This means that for all pallet positions where half pallets are stored, there is unutilized space. The group external pallets are handled with reach trucks. The DM pallets, in both the DM engine blocks group and other DM material group, are handled by counterweight trucks since the majority of them are heavy, and it is easier for counterweight trucks to handle such SKUs efficiently. Regarding boxes, they are stored in their own racking system, also single-deep. From this racking system, they are picked out by hand onto a special box platform (Swe: "rack"), which is handled with a reach truck. According to interviews, these racking and platform equipment enable ergonomic handling of the boxes. The cartons are stored on pallets in a racking system where shelves can be pulled out, which makes the activity of picking cartons more ergonomic since the picker does not need to reach far into the rack to pick a carton. The same goes for piece picked SKUs. An overview of the equipment used for the different groups is presented in Table 4.5.

Table 4.5: An overview of the equipment used in the warehouse.

Group	Storing equipment	Handling equipment
External pallets	Single-deep racks and multiple deep flow racks	Reach truck and Turret trucks
Boxes	single-deep racks	Reach truck
DM engine blocks	Single-deep racks	Counterbalance truck
Other DM material	Single-deep racks	Counterbalance truck
Carton picked SKUs	Single-deep racks where each storage location can be pulled out	Reach truck
Piece picked SKUs	Single-deep racks where each storage location can be pulled out	Reach truck

Noteworthy is also that when estimating the capacity need for 20YY in terms of storing equipment, storage location margins must be included. According to Scania, it is reasonable to estimate that the depth of racks equals the depth of the SKU that is stored in the rack. In width, a pallet storage location requires the size of the SKU plus an additional seven and a half centimeters on each side, while a box storage location requires the size of the SKU plus an additional five centimeters on each side. To pick efficiently, a margin of around ten centimeters is needed above the SKU to the next shelf. Another finding from interviews is that put away and picking can be made faster if the shelves in the racking systems on both sides of the aisles are of the same height. This leads to less confusion since the corresponding shelf numbers will start at the same height on both sides of the aisle.

4.2.3 Information Systems

Scania currently uses the information system SIMAS within the warehouse, which is built and maintained in-house. By 20YY, all functionalities available today are expected to remain, and more functionalities are expected to be introduced. For example, it is expected that the system will have capabilities to take multiple parameters into account when assigning storage locations for put away and generate pick lists in a smart sequence. The final complexity of the WMS is decided centrally and the same WMS will be implemented in all logistics centers in Södertälje. It should be considered that the configuration can not propose options that require complexity beyond what a normal WMS can handle.

4.2.4 Labor and Activities

The warehouse operates 16 hours a day on a two-shift structure, where the first shift is from 7 am to 3 pm, and the second shift is from 3 pm to 11 pm. The operating hours and shift structure of the assembly depict the operating hours in the warehouse. The new warehouse configuration can not require a change of the working hours structure, which is expected to be the same in 20YY as in 2024. Within the warehouse team, different working groups are responsible for different activities inside the warehouse. All employees are hired by Scania, and external labor is rarely or never contracted. The activities include receiving, put away, picking, and delivering to customers, as well as support activities such as sorting, labeling, quality checking, replenishment between storage areas, and improvement work.

4.3 Warehouse Operations

4.3.1 Receiving

Receiving is not in the scope of the recommendation, however, it affects the inbound flows and other operations, why it is important to get an understanding of the process. Goods arrive at the warehouse from 7 am to 11 pm, and the receiving dock can effectively and safely handle about XX pallets per shift.

In 2024, the inbound area handles about XX to XX trucks and XX pallets per day Monday to Thursday, and somewhat fewer pallets on Friday. Around XX external trucks arrive in the daytime shift and XX in the evening shift. The evening shift trucks generally carry slightly larger loads. Sometimes, additional express trucks arrive with special deliveries. On top of this, about XX trucks arrive per day, once or twice an hour, from an internal supplier. The internal supplier delivers the strategic DM SKUs, both the DM engine blocks and the other DM material.

There are two spots in the goods receiving dock designated for external trucks. When an external supplier arrives, the transport is registered and the goods are released from the truck. On average, XX pallets per truck are unloaded every 15 minutes, and at maximum, XX pallets per truck can be unloaded every 15 minutes. This means that a total of XX pallets are unloaded on average, with a peak of XX pallets. A paper with information is printed and nailed on each pallet from the delivery, and the pallets are controlled and scanned. It is expected that this operation will be digitalized by 20YY. Pallets are then sorted into stacks based on what part of the warehouse they are to be stored in. The scanning and sorting operations are a bottleneck, so the flow into the warehouse is about XX pallets per 15 minutes. The internal supplier trucks are unloaded in a separate part of the goods receiving area.

Assuming that the number of unit loads arriving at the warehouse daily changes linearly with the total number of assembled engines, the average inbound volume will be XX pallets in 20YY. This is XX% of the 2024 volume, and about 30% below the volume that the goods receiving area can handle efficiently and safely. This means that the receiving area will likely be able to operate efficiently and safely in 20YY if its configuration remains the same as today. If the receiving operations are simplified with digitalization, the inbound volume to the warehouse may be slightly above the 2024 number. This dictates the capacity that the warehouse needs to handle in the inbound and put away operations. The arrival schedule is considered stable throughout the day, week, and year so the warehouse capacity need can be based on average volumes.

What gates the materials flow through inbound have been set to remain the same in 20YY. This means that all external pallets arrive through the pallet roll rack P, the boxes through gate F, DM engine blocks through gate E, and the other DM material through gate D. On average, three external pallets are stacked when transported inbound, and 35 boxes are transported together in the same inbound travel. The DM engine blocks are transported two at a time inbound, while other DM material pallets are transported one at a time. This inbound flow can be seen in Figure 4.6.

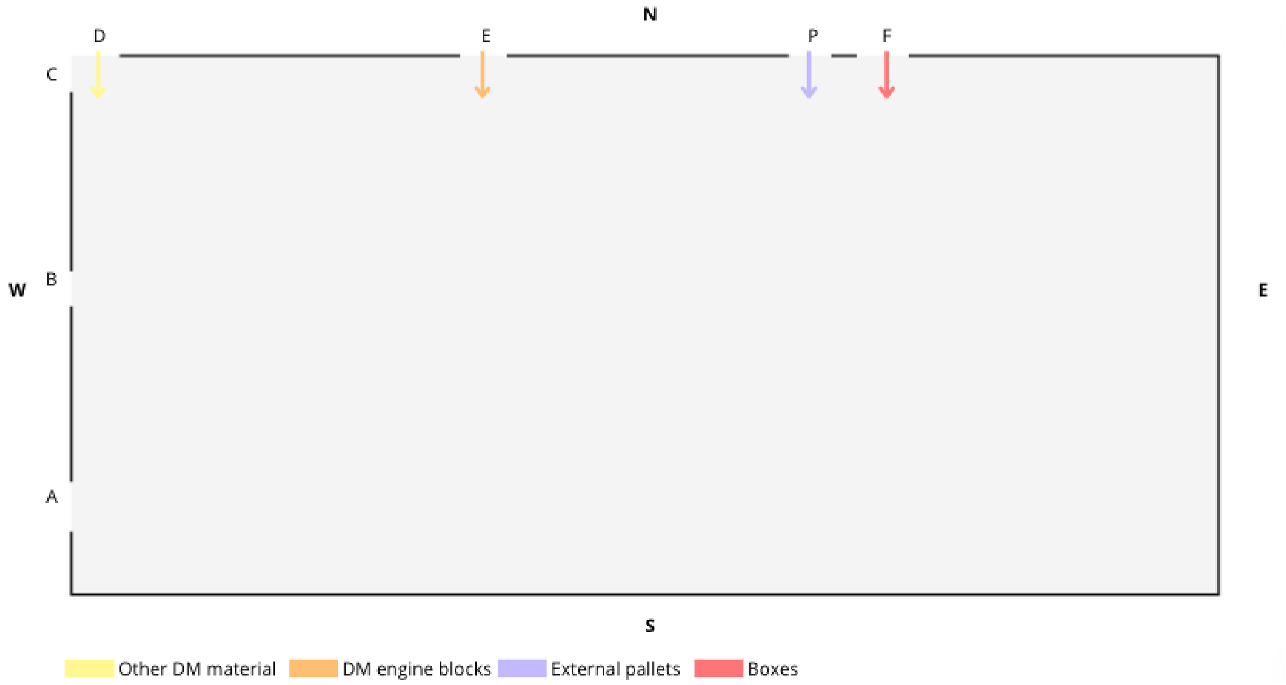


Figure 4.6: The gates used for the different inbound flows.

4.3.2 Put Away and Storage

There are no specific requirements on how the put away and storage operations should be configured in 20YY. An important finding from interviews is however that put away operations are always downgraded compared to picking operations since orders must be delivered to the customers within two hours of being placed.

4.3.3 Picking

The main customers, which as previously mentioned are DW, V8, and PS, require the SKUs to be presented with the same equipment as today. They also require that the SKUs arrive sorted per customer. This affects how picking can be performed, and the equipment limits the possible pick list length. Therefore, it is important to understand how the SKUs are picked today. For external pallets, the pick lines are printed on paper, and pick lists are manually put together by an employee in the pallet storage area. When putting the pick lists together, they consider what customer the item is going to, and prioritize the weight of each SKU, the time when the order was placed, and where in the warehouse the SKU are stored to make an efficient stack and pick route. This process of putting together pick lists could likely be digitalized by 20YY, however, the prioritization order of how stacks are built should remain the same.

For boxes, a truck driver receives a pick list on a digital screen, picks up an empty box platform, and fills it with boxes according to the pick list. The pick lists can include up to 20 boxes, which is the maximum number a platform going to DW and V8 can have. For PS deliveries, the pick lists can be a maximum of 16 pick lines long. On average, as mentioned in the order characteristics section, the pick lists are 15 lines long for boxes. The use of platforms in picking operations for boxes will remain the same in 20YY.

Regarding the DM engine blocks, they are used for every engine and are picked according to a set schedule. The DW DM engine block SKUs are picked four at a time and put on a train. The V8 DM engine blocks are picked two at a time. The other DM material is picked one pallet at a time.

For carton picking and piece picking, the operators receive prepared pick lists with multiple pick lines, physical or digital. For cartons, the picks are made onto a special pallet marked with 25 separate spots, sequenced from one to 25. The pick list sequence is based on the assembly sequence specified by the customer. In practice, this means that if the same SKU is to be put as carton number one and number 25 according to the pick list, the operator needs to travel back and forth two times to the same storage location, since he or she picks from the top to the bottom according to the pick list. The carton then also gets a label, including the number of items inside the carton and to what address on the assembly line it is going. Orders to the carton storage area are picked two at a time. For pieces, there is no limit as to how many items can be placed in the same order, but in general, a picker picks four to five orders at the same time, which all are put on the same pallet and separated by putting pieces from different orders in different plastic bags on the pallet. When the pick lists for carton and piece picked SKUs are completed, the pallets are manually checked to verify that they are correct. This happens in a workstation which is one of the so-called other areas. The carton picking and piece picking process will look the same in 20YY. What might be changed is how the pick lists for cartons are generated, depending on the information system's capabilities.

4.3.4 Shipping

The main customers require the SKUs to be transported through the same gates as today. This means that DW external pallets, DM engine blocks, and other DM material must be delivered by specific trains directly to the assembly line, through gate C. The DW DM engine block train transports four pallets at a time, while the DW external pallet train carries on average 12 SKUs. At set intervals depending on the rate of production, about every 15 to 30 minutes, an operator from the engine assembly enters the warehouse in a special truck. He or she unloads a train with empty pallets, picks up a full train, and drives it into the engine assembly. For V8 external pallets, they must be delivered to their handover area inside the warehouse on the west wall. From there, they are picked up by engine assembly workers and transported through gate B. The V8 DM engine blocks are delivered two and two straight to the assembly line through gate B, and other DM material for V8 are delivered through gate A to a handover area inside the engine assembly.

Both DW boxes and V8 boxes are delivered to a box handover area inside the engine assembly via gate A. This area can store ten box platforms next to each other. Once a filled platform has been placed in one of the available places, the work for the truck driver from the warehouse is completed and the responsibility is forwarded to an operator in the engine assembly. If any empty platforms are occupying one of the ten spots, the truck operator brings the platform back to where the boxes are stored on his or her way back to the warehouse.

Carton picked SKUs are delivered on their special pallets, stacked four and four, and piece picked SKUs are delivered in plastic bags on pallets, both through gate A. For PS, all deliveries are delivered to the handover area next to gate E, through which they are later transported. All outbound flows together with the location of the V8 and PS handover areas can be seen in Figure 4.7.

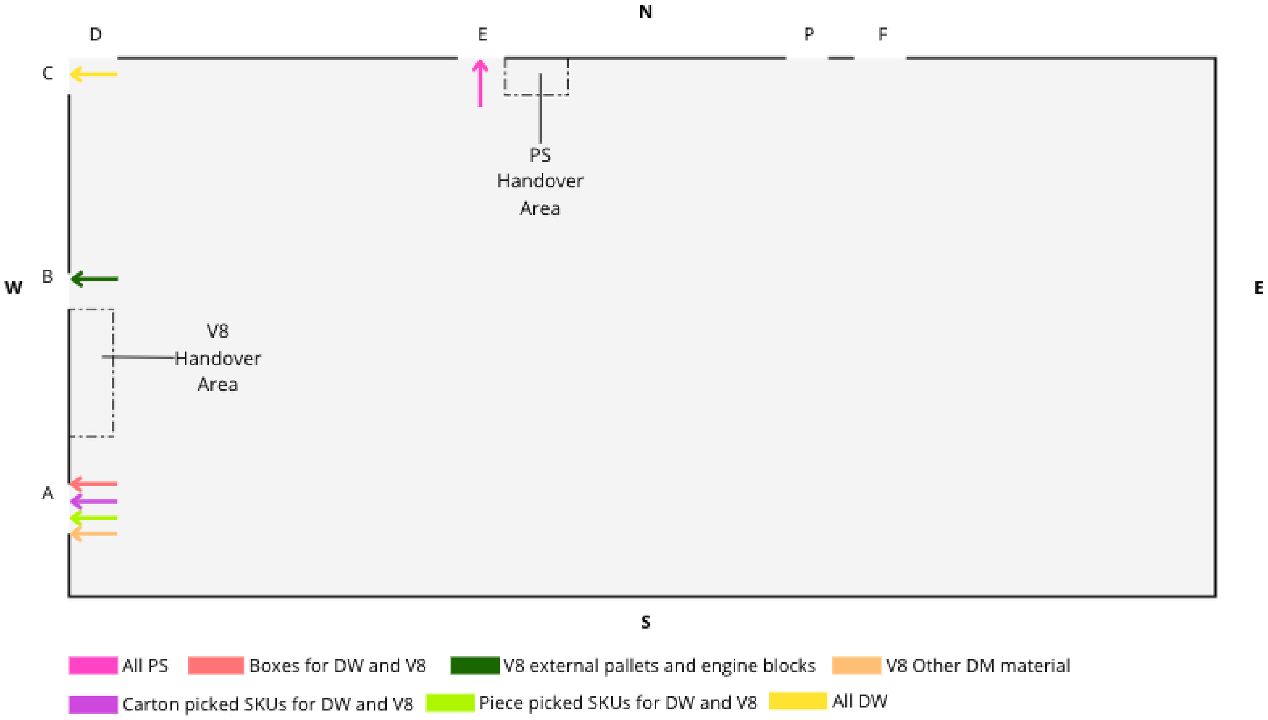


Figure 4.7: The outbound flows, and the location of the V8 and PS handover areas.

The number of travels inbound and outbound can be calculated by crossing the data of how many items are transported together inbound and outbound with the order data. For example, each order for an external pallet corresponds to picking a stack of three external pallets, and as previously mentioned, 12 picked DW pallets are consolidated in a train before being transported outbound. This means that for DW external pallets, one outbound travel means 12 separate picks and four orders, on average. The same logic can be followed to perform calculations for the other groups and customers as well. The result of the calculations can be seen in Table 4.6. Note that no calculations are done for the piece picked SKUs since data is lacking.

Table 4.6: A comparison of the number of inbound and outbound travels per group and customer.

Group and customer	**SKUs picked**	**SKUs per inbound travel**	**Inbound travels**	**SKUs per outbound travel**	**Outbound travels**
DW external pallets	1033	3	344	12	86
V8 external pallets	267	3	89	3	89
PS external pallets	52	3	17	3	17
Others external pallets	318	3	106	3	106
DW boxes	577	35	16	15	38
V8 boxes	284	35	8	15	19
PS boxes	305	35	9	15	20
Others boxes	201	35	6	15	13
DW DM engine blocks	XX	2	XX	4	XX
V8 DM engine blocks	XX	2	XX	2	XX
DW other DM material	140	1	140	12	12
V8 other DM material	28	1	28	1	28
Carton picked SKUs	993	More than 30	More than 33	100	10

Chapter 5

Analysis

This chapter fulfills the first research objective. It begins with synthesizing the empirical findings to identify the overall warehouse context. Thereafter, the theory presented in the frame of reference chapter is used to decide what the most suitable configuration element options are, based on the identified context.

5.1 Contextual Factors

The range of flows, products, orders, and customers identified in the empirical findings chapter indicate a high level of complexity for the warehouse, and many configuration elements need to be considered in the analysis. To conclude which configuration element options are the most suitable, the overall warehouse context must be understood, in accordance with contingency theory (Kembro & Norrman 2021). This begins with summarizing the warehouse context for each relevant contextual factor. The result of this analysis is presented in Table 5.1 below.

Table 5.1: The identified relevant contextual factors for this thesis, the configuration elements they affect, and the insights on the warehouse context from empirical findings.

Contextual factor	**Warehouse configuration element influenced**	**The warehouse context for each contextual factor**
Warehouse type and role	Overall operations	Pre-assembly warehouse that needs to supply the engine assembly with components
Product characteristics	Space needed, and the storing and handling equipment needed	Large number of total SKUs but great varieties in number of SKUs, weight, size and type between storage areas
Order characteristics	Picking strategy and picking method	Large number of total orders but great varieties in number of orders, order lines per order and SKUs per order between storage areas
Customer characteristics	Assortment	Three main customers with different requirements on outbound flow and delivery
Demand profile	Storage allocation method, flexibility of the warehouse	Large number of total picks but great varieties in number of picks between storage areas, and no significant seasonality patterns

Based on the above table, it is clear that the context for most contextual factors varies a lot. This is because the different groups of SKUs have varying product characteristics, order characteristics, customer characteristics, and demand profiles. To get an overview of the overall warehouse context, the contexts for the different groups are mapped together in Figure 5.1 below. The concept of the map is highly inspired by Kembro and Norrman (2021), who map contextual factors in a web-like structure to understand and visualize companies' contextual profiles.

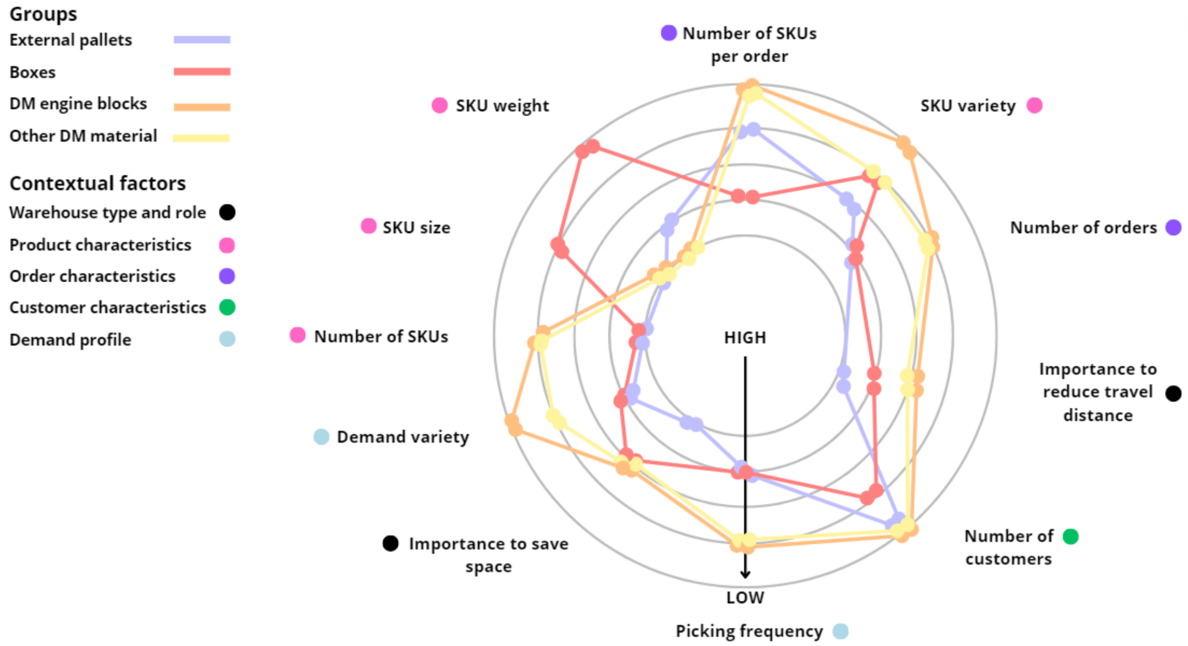


Figure 5.1: The contextual factors and the context for each group of SKUs, similar to the mapping of companies' contextual factors originally done by Kembro and Norrman (2021).

The above figure illustrates the contextual factors for the different SKU groups inside the warehouse. From the figure, a first important conclusion can be drawn, which is that the different groups operate in different contexts. Due to this, their warehouse design, resources, and operations should be configured separately, to better match their specific context (Kembro & Norrman 2021). Therefore, the approach in the following sections of this chapter is to do separate analyses for the different groups and regard them as separate storage areas. The carton picked SKUs and piece picked SKUs are not considered in any analysis, but are included in the final recommendation, as previously mentioned. Nonetheless, what contextual factor influences what configuration element and what context each configuration element option is suitable in has been identified. Furthermore, the context for each storage area has been understood. Based on this, analyses can be made on what configuration element options are the most suitable for each storage area, which concludes the first research objective.

5.2 Warehouse Design and Resources

In this section, design decisions are made for the different storage areas. The decisions are shown by bringing in the tables on the different configuration elements presented in the frame of reference chapter and marking what configuration element options are the most suitable for each storage area, depending on the storage areas' contexts.

One main goal of the reconfiguration is to use the space inside the warehouse more effectively, and ideally eliminate the need for an external warehouse. With this goal, the fishbone layout is not an option for aisle configuration since it is space-consuming (Bartholdi & Hackman 2019). According to Bartholdi and Hackman (2019), the parallel aisles configuration is the most space saving aisle configuration, hence it is selected as a suitable aisle configuration for all storage areas. This design decision is highlighted in Table 5.2 below. Cross-aisles require more space than parallel aisles (Bartholdi & Hackman 2019), why it is not selected as the suitable aisle configuration. With that said, a priority according to Scania Production Systems is also to be cost-effective, which can be achieved through shorter travel distances and less double handling since those are large cost drivers in warehouses (Bartholdi & Hackman 2019; Gildebrand & Josefsson 2014). Cross-aisles generally reduce travel times compared to parallel aisles (Bartholdi & Hackman 2019), why such an aisle configuration could be considered if the final configuration ends up with slack space.

Table 5.2: The suitable aisle configuration based on the storage areas' context.

Aisle configuration option	**Suitable context**	**External pallets**	**Boxes**	**DM engine blocks**	**Other DM material**
Parallel aisles	Need to save space	X	X	X	X
Cross-aisles	Reducing travel time is more important than saving space, but saving space is also a goal				
Fishbone layout	Reducing travel time is important and space is not a constraint				

To decrease travel distance, aisles should run parallel to the material flow (Bartholdi & Hackman 2019). The flow direction can be determined by looking at Figure 4.6 and Figure 4.7 in the empirical findings chapter. The material flows for all external pallets and for DM engine blocks run from east to west, so their aisles should run parallel to the north wall. For other DM material for V8, the material flow runs from north to south, so their aisle should be parallel to the west wall. The other DM material for DW has the in- and outbound gates next to each other on each side of the northwest corner so these SKUs could be placed parallel to either the north or west wall. The other DM material to V8 and DW will be stored together, based on their similar context, their common inbound deliveries and workforce, and the fact that they are so few. Therefore, the V8 SKUs of this storage area dictate the direction of the aisles. The main material flow for boxes goes from northeast to southwest, so aisles should be parallel to the west wall if the inbound flow is premiered, and parallel to the north wall if the outbound flow is premiered. It should also be considered that PS boxes are shipped through gate E, on the north wall. An overview of the suitable aisle direction per storage area is presented in Table 5.3.

Table 5.3: The suitable direction of aisles based on the storage areas' context.

Storage areas	**Aisles parallel to**
External pallets	North wall
Boxes	West wall if the inbound flow is premiered, and north wall if the outbound flow is premiered
DM engine blocks	North wall
Other DM material	West wall

To save space, the three DM engine block SKUs are prime candidates for being stored in deep lanes. Placing them in high racks is time-consuming and means large damage risks due to their heavy weight, why it is not a suitable space saving measure. Instead, storing them in lanes that are four pallets deep is a suitable option, since it fits the SKUs constant demand and matches the fact that they are picked in groups of four or two, which minimizes the honeycombing effect (Bartholdi & Hackman 2019). By storing the same SKU in depth, the risk of double handling is also minimized (Bartholdi & Hackman 2019). Furthermore, by storing the SKUs on the floor, no special equipment is needed despite the deep lanes. Storing them on the floor is also justified by their heavy weight. If the SKUs are stored straight on the floor in deep lanes, they should be put away and picked from different sides to follow FIFO and eliminate double handling. This arrangement would require eleven lanes in total, covering an area of approximately 55 square meters, for their 44 storage locations.

Regarding other DM material, external pallets, and boxes, it is possible that some of these SKUs could meet the criteria for deeper lane storage. However, the lack of precise future data on what engine variants will be demanded in 20YY makes it difficult to determine which SKUs and how many will qualify for deep lanes by 20YY. Given this uncertainty and the imperative to adhere to FIFO while still minimizing double handling, it is reasonable and advised to stick with single-deep lanes for all other storage areas.

Since double handling should be avoided and the stacking limit for SKUs is way below the available facility height, racking systems should be used in all storage areas besides the one for DM engine blocks. External pallets and boxes should utilize the full available warehouse height of nine meters but the heavy SKUs in these areas should be stored at floor level to maintain safe and ergonomic operations. For other DM material, where all SKUs are relatively heavy, the rack should be lower and instead be longer. A longer rack is also positive from a congestion standpoint in this frequently picked storage area since a longer rack leads to fewer SKUs being picked from the same aisle space. Further, the benefits of storing the SKUs in racking systems are, according to Bartholdi and Hackman (2019), that the products are protected from damage and that the work environment becomes safer. This is important since some SKUs are valuable, and safety is a priority for Scania.

Since the warehouse is large and has many storage locations in total, mixed-width aisles are suitable for finding the balance between saving space and making the operations efficient (Mowrey & Parikh 2014). What areas should have minimum aisle width and what areas deserve extra aisle width, which according to Scania minimizes damage risk and increases efficiency, depends on the contextual factor demand profile. Areas with many put aways and high picking frequency are in greater need of wider aisles, which means at least three and a half meters to allow for two-way traffic, but preferably four meters according to warehouse workers. Storage areas, or zones within storage areas, with little activity, can have narrow aisles to save space. Since the narrow width of aisles and equipment used in the box storage area today enables ergonomic handling, the same aisle width should be used in 20YY in that storage area. The storage area for other DM material, characterized by intense activity concentrated in a few places of the aisle, warrants priority for wider two-way aisles, totaling four meters, to facilitate smoother operations. If certain aisles in the external pallet storage area become more congested than others due to the storage allocation policy, it should be prioritized to give these aisles extra width, up to four meters, and compromise on the low activity aisles by making them narrow. All of these design decisions regarding space saving measures are highlighted in Table 5.4.

Table 5.4: The suitable space saving measure based on the storage areas' context.

Space saving measure	**Suitable context**	**External pallets**	**Boxes**	**DM engine blocks**	**Other DM material**
Deep lanes	Need to save space, the number stored of the same SKU is at least as large as the lane is deep, and honeycombing is not a problem			X	
Stacking	Need to save space, and SKUs are non-fragile and light				
Racking	Need to save space, SKUs are fragile and/or heavy, and double handling and honeycombing should be avoided	X	X		X
Mixed-width aisles	Large warehouse with low space cost, and/or many aisles, and/or high throughput	X			

What storing equipment is suitable depends on the warehouse type and role and product characteristics, and since it was decided to not use deep lanes for any other storage area than for DM engine blocks, all racking systems should only be single-deep. If double-deep racks are used in the future for frequently picked SKUs, they should be flow-through since they enable FIFO and are faster to put away and pick from compared to drive-through racks (Bartholdi & Hackman 2019). For the DM engine blocks, which are to be stored on the floor, no storing equipment is relevant. These design decisions are highlighted in Table 5.5.

Table 5.5: The suitable storing equipment based on the storage areas' context.

Storing equipment	**Suitable context**	**External pallets**	**Boxes**	**DM engine blocks**	**Other DM material**
Single-deep rack	Need to follow FIFO	X	X		X
Double-deep rack	Need to save space, and SKUs can follow LIFO				
Push-back rack	Need to save space and have easier access than double-deep racks can provide, and SKUs can follow LIFO				
Flow-through rack	Need to follow FIFO, need to save space, need to avoid interference between put away and picking, and SKUs are picked frequently				
Drive-in rack	Need to save space, SKUs can follow LIFO, and slower put away and picking is not a problem				
Drive-through rack	Need to follow FIFO, need to save space, and slower put away and picking is not a problem				

Utilizing the full facility height and single-deep racking systems enables 26 boxes to be stored in height. With such a setup, a total of 208 rack meters are needed for the box storage area. The total rack length needed for external pallets depends on whether the racks are designed for full pallets or divided into half and full pallet racks, and for what SKU height the racks are designed. This also affects the total area needed for the external pallet storage area since a division between full and half pallets also affects the depth needed for the racks. If all aisles are made three and a half meters wide, the full available ceiling height is utilized, and all racks are designed to fit the tallest full pallet, 1821 meters of racks and a total area of 5409 square meters, are needed for the external pallet storage area. This is not feasible considering that the total warehouse space is 8806 square meters and the other areas (coffee areas, working stations, truck parking areas, and so on) require 1535 square meters, leaving only 1862 square meters for all other storage areas, aisles, and operations.

Similar calculations for different combinations of rack and aisle sizes in the external pallet storage area are summarized in Table 5.6. The rack size column tells what size the racks are designed for, and the dimensions can be seen in 4.2. The aisle size tells whether the aisles are two-way aisles (three and a half meters) or narrow aisles that only allow one-way traffic (one point ninety-six meters). The total rack length tells how many rack meters are needed with each rack and aisle combination, and the total area tells how many square meters the external pallet storage would require for each combination. The total space savings are compared to the least space-effective design, which is where all pallet locations are designed to fit the tallest full pallet. All calculations are based on the approximation that each rack meter requires aisle space of one meter times half the width of the aisle since the aisle is shared between two racks. Moreover, ten centimeters of slack space above each pallet until the next shelf is accounted for, as well as the need for seven and a half centimeters between each pallet.

Table 5.6: Rack and aisle size options to save space in the external pallet storage area.

External pallets				
Rack size	**Aisle size**	**Total rack length (meters)**	**Total area (square meters)**	**Total space savings (square meters)**
All fit tallest full pallet	Two-way	1818	5399	0
All fit full pallet 14	Two-way	1540	4574	825
Tallest half pallet and tallest full pallet	Two-way	1533	4402	997
All fit tallest full pallet	Narrow	18218	3999	1400
Half pallet 72 and full pallet 14	Two-way	1233	3561	1838
Half pallet 72 and full pallet 33	Two-way	1189	3380	2019
Tallest half pallet and tallest full pallet	Narrow	1533	3222	2177
Half pallet 72 and full pallet 14	Narrow	1233	2612	2787
Half pallet 72 and full pallet 33	Narrow	1189	2462	2937

There are 198 full pallets taller than the 14 pallet, and 120 half pallets taller than the 72 pallet. Therefore, if racks are designed for the 14 full pallet and the 72 half pallet, 198 and 120 locations respectively must be designed to fit the taller full and half pallets. This is such a small number, so they could easily fit on the top shelves or the floor locations, which are natural choices for the tallest pallets. The top shelves are favorable since they do not require any re-racking of the racking system and therefore allow for as much space saving as possible. The floor positions are also good choices since they are suitable for heavy pallets, which is often the case for taller pallets. Storing the tallest pallet on floor positions would require the first rack level to be taller than the other levels, which would lead to a bit of unutilized space in height. With racking systems designed for the 14 and 72 pallets, large space savings would be yielded without compromising efficiency, and is, therefore, the recommended racking design for this storage area. With this design, the external pallet storage area would require 980 meters of racks for full pallets and 253 meters of racks for half pallets.

If designing the racks for the 33 full pallet, about 150 square meters would be saved compared to designing for the 14 pallet. However, 1827 full pallets are taller than the 33 pallet which is more than the total number of top positions or floor positions. This would mean that 1827 pallet locations in the racking system would need to be taller than the standard following the size of the 33 pallet, which would reduce the space savings. With this in mind, it is not recommended to design the full pallet shelves for SKUs smaller than the 14 pallet.

Having narrow aisles in the external pallet storage area is effective from a space saving perspective, and it does not make the storage allocation possibilities less. However, whether narrow aisles are efficient and cost-effective or not can be determined first when the number of activities (picks and put aways) per hour and aisle is known. If the number is high enough that more than one person needs to work in the aisle at the same time, the one-way traffic narrow aisles are not suitable. If the number of activities is too low, the operator either spends time waiting for work or has to work in several aisles. The first alternative is costly, and the second alternative leads to slow put away and picking operations since the narrow aisle trucks only are efficient when working in the same aisle (Bartholdi & Hackman 2019). If the number of activities is just enough for one operator to be occupied with work in one aisle at all times, and if the activities are evenly spread out over the aisles and throughout the day, narrow aisles can be a suitable configuration element option. A decision on whether or not narrow aisles are recommended can be determined first when all storage areas are configured together in the recommendation chapter.

With the already made design decisions, the choices for handling equipment are made according to Table 5.7. The choices are affected by the product characteristics and the selected storing equipment. Since all DM SKUs are heavy and stored at low levels, the counterbalance trucks should be used in the storage areas for DM engine blocks and other DM material (Bartholdi & Hackman 2019). In the external pallet and box storage area, where SKUs will be stored in high racking systems, reach trucks and turret trucks should be used, depending on how narrow the aisles are (Bartholdi & Hackman 2019). Turret trucks are used in narrow aisles today, so the criterion of a solid warehouse floor is assumed to be met in 20YY as well.

Table 5.7: The suitable handling equipment based on the storage areas' context.

Handling equipment	**Suitable context**	**External pallets**	**Boxes**	**DM engine blocks**	**Other DM material**
Counter-balance truck	Trucks need to function well in different types of aisles, SKUs are not stored higher than six meters, and aisles are relatively wide			X	X
Reach truck	SKUs are stored higher than six meters, and aisles are narrow	X	X		
Turret truck	SKUs are stored high, aisles are very narrow, and the floor is solid	X	X		

To decrease the total travel time in the warehouse, the number of inbound and outbound travels to and from each storage area should be considered when placing the storage areas in the warehouse facility. From Table 4.6, the number of inbound and outbound travels can be compared per storage area and customer. DW external pallets, DW DM engine blocks, and DW other DM material have more inbound travels than outbound travels, thus travel distance is minimized if they are located close to their inbound gates. Boxes have more outbound travel, so their travel distance is minimized if they are placed closer to their outbound gate. However, the boxes have two different outbound gates on two different sides of the building (gate A and gate E). Since there are more outbound travels through gate A, a location close to this gate is prioritized. For the other storage areas, the ratio between inbound and outbound is one, so from a travel time perspective it does not matter if they are located closer to their inbound or outbound gate.

In Tables 5.8 and 5.9, the storage areas are ranked based on their number of inbound and outbound travels. To decrease the total travel distance when storage areas compete for the same space, the top-ranked areas should be premiered to be placed close to their inbound and outbound areas. However, important to consider is also that the customers have different requirements on the outbound flows, why the number of outbound travels from each storage area to each customer is also presented, in Table 5.10.

Table 5.8: The priority amongst storage areas in terms of placement close to their inbound gate, based on the storage areas' context.

Ranking	**Storage area**	**Inbound travels**
1	External pallets	556
2	Other DM material	168
3	DM engine blocks	97
4	Boxes	39

Table 5.9: The priority amongst storage areas in terms of placement close to their outbound gate, based on the storage areas' context.

Ranking	Storage area	Outbound travels
1	External pallets	298
2	Boxes	91
3	DM engine blocks	61
4	Other DM material	40

Table 5.10: The priority amongst storage areas and customers in terms of placement close to their outbound gate, based on the storage areas' context.

Ranking	Storage area	Outbound travels
1	Others external pallets	106
2	V8 external pallets	89
3	DW external pallets	86
4	DW boxes	38
5	DW DM engine blocks	37
6	V8 other DM material	28
7	V8 DM engine blocks	24
8	PS boxes	17
9	V8 boxes	19
10	PS external pallets	17
11	Others boxes	13
12	DW other DM material	12

5.3 Warehouse Operations

Starting with put away, the storage allocation method for each storage area is to be determined. It is affected by the storage areas' product characteristics, customer characteristics, and demand profiles. According to the design decision to adjust the shelves in the racking system according to SKU size, SKUs in the external pallet storage area must at least be allocated based on the SKU attribute SKU dimensions. The half and full pallets should be allocated to different racks, and the tallest SKUs should be allocated to the top or floor positions. The empirical findings also show that the allocation method should consider the SKU attributes weight and unit cost. The heavy and high-value SKUs should be placed on the floor positions, or at least on low levels, to decrease the risk of damage. Regarding the three DM engine blocks, they should have a dedicated storage allocation with only one type of engine block stored in each lane.

From the empirical findings, allocating SKUs to zones based on what customer they go to can decrease picker interference and travel distance in the storage areas for external pallets, boxes, and other DM material. First of all, each customer has different requirements for outbound flows, and the storage locations that minimize travel distance in these areas are therefore different for DW, V8, and PS. Starting with the external pallet storage area, DW requires six times as many storage locations as V8 and eight times as many storage locations as PS. Since the pick lists only contain SKUs going to the same customer, the distance for picking V8 and PS is drastically decreased if they are stored separately. This is because only one or a few aisles will have to be traveled to complete a pick list, instead of potentially the whole storage area. Moving on to the box storage area, the total travel distance is decreased if the number of aisles traveled per pick list is decreased, which happens if SKUs going to the same delivery address on the line are located in one or a few aisles next to each other. This is because each box platform can only be filled with SKUs going to the same delivery address on the line. For other DM material, interference between the pickers can be decreased by placing V8 SKUs on the end of the rack which is closest to its outbound flow, and the DW SKUs on the other end of the rack. This is at least true if more than one picker works in the storage area at the same time.

Since the aim of the reconfiguration is to both save space and reduce travel and retrieval time, CBS can be useful (Chan & Chan 2011; Guo et al. 2016; Petersen & Aase 2004; Rao & Adil 2015). For the benefits to be gained from this storage allocation method, the pick lists should be short and the picking frequency curves should be skewed (Petersen & Aase 2004). This is the case for external pallets and other DM material, but not for boxes. For other DM material, the whole storage area is so small that there is little to win from placing the A group at one end of the rack. Further, a side effect would be increased congestion risk (Chan & Chan 2011). Placing the most frequently picked SKUs on the lowest shelves decreases retrieval time and congestion, and is therefore considered a suitable option.

Since it is already stated that the external pallets should be placed in racks based on what customers they go to, a deeper analysis must be made of whether the customer-specific picking frequency curves are skewed or not. For DW, 20% of SKUs stand for 60% of the total picks made in the external pallet storage area, and for V8 20% of SKUs stand for 63% of the total picks made in the external pallet area, so neither of these curves are very skewed. For PS, 20% of SKUs stand for 73% of the total picks made in the external pallet storage area, so its picking frequency curve is moderately skewed. Therefore, benefits could be gained from applying CBS in the PS aisles. Next, it must be decided whether CBS should be applied across aisle or within aisle for the PS aisles and, if across aisle, whether it should be applied horizontally or vertically. If the area gets several aisles, it can be beneficial to put the A SKUs together to decrease the travel between aisles. If the aisles are placed so that the inbound and outbound areas are on the same side of the rack, it can be beneficial to put the A SKUs closest to the depot. If not, placing A SKUs on the bottom shelves would decrease congestion risk and retrieval time. Since saving space is important and there is no value in applying a CBS for the DW and V8 external pallets, or any boxes, these SKUs can be allocated randomly within their dedicated customer and SKU size zone. Due to the one-to-one ratio between the put away and pick travel for these storage areas, the closest storage allocation method adds no value compared to just random in terms of total distance traveled. By allocating them randomly within their dedicated customer and SKU size zone, the number of classes is kept low, which makes the storage area more flexible (Petersen & Aase 2004).

To conclude, in the external pallet storage area, the SKUs should be divided into zones based on customer, and for DW and V8, random storage should be applied. For PS, CBS should be applied. Whether a within aisle, across aisle, vertical or horizontal allocation is the best for the PS external pallets must be further investigated when the length of racks, number of aisles, and their location in the warehouse is decided. In the box storage area, SKUs should be allocated based on what delivery address they go to. The DM engine blocks should have a dedicated allocation, and for other DM material, SKUs should be allocated based on what customer they go to and be placed vertically based on their picking frequency. The decisions on storage allocation method are presented in Table 5.11 below.

Table 5.11: The suitable storage allocation methods, based on the storage areas' context.

Storage allocation method	**Suitable context**	**External pallets**	**Boxes**	**DM engine blocks**	**Other DM material**
Dedicated storage	Storing small and frequently picked SKUs, and labor efficiency is highly valued			X	
Full turnover storage	Saving travel time is important, the picking frequency curve is skewed, and pick lists are short				
Random storage	Saving space is more important than reducing travel time	X	X		
Closest Storage	Saving space and reducing travel time is equally important				
Affinity storage	Reducing travel time is more important than saving space, certain SKUs are frequently picked together, and pick list sequences rarely change				
CBS	Saving space and reducing travel time are both important, the picking frequency curve is skewed, and pick lists are short	X			X
Storage based on other SKU attributes than picking frequency	Being able to allocate SKUs based on other attributes than picking frequency is important to enable special handling, to save space or to reduce travel time	X	X		X

Moving on to the picking strategy, for external pallets, DM engine blocks, and other DM material, multiple pickers should pick to the same customer to ensure service levels are met. This could be considered a form of parallel picking (Bartholdi & Hackman 2019), but the consolidation naturally happens in the handover area and trains. For boxes, serial picking should be applied, meaning that only one picker picks one order at a time, to avoid congestion and pickers waiting for each other in the narrow aisles. The design decisions for picking strategy can be seen in Table 5.12.

Table 5.12: The suitable picking strategies, based on the storage areas' context.

Picking strategy	**Suitable context**	**External pallets**	**Boxes**	**DM engine blocks**	**Other DM material**
Serial picking	Coordination and consolidation of work between multiple pickers should be avoided, it is not possible for multiple pickers to pick the same order, or picking speed is not a major priority		X		
Parallel picking	Picking speed is important, and orders can be consolidated after picking	X		X	X

According to Bartholdi and Hackman (2019), the picking strategy, order characteristics, and the demand profile determine what picking method is suitable. All storage areas receive many orders every day. For external pallets, the order size is small and there are many SKUs stored in the area, so zone picking is suitable. For boxes, many SKUs are stored in the storage area, the order size is on average 15 order lines which is relatively large, so zone picking or wave picking is suitable for those SKUs. For DM engine blocks and other DM material, few SKUs are stored, and there are many orders of small size so batch picking is suitable. The risk of sorting error, which can follow a batch picking method (Bartholdi & Hackman 2019; Gu et al. 2010; Manzini 2012; Peterson & Aase 2004), is not a problem in this case since the DM SKUs are not sorted after picking. See these design decisions highlighted in Table 5.13.

Table 5.13: The suitable picking methods, based on the storage areas' context.

Picking method	**Suitable context**	**External pallets**	**Boxes**	**DM engine blocks**	**Other DM material**
Single order picking	Few orders and large order size				
Batch picking	Many orders and small order size			X	X
Zone picking	Many orders, small to moderate order size, and the number of SKUs in the storage area is large	X	X		
Wave picking	Very large amount of orders, moderate to large order size, and the number of SKUs in the storage area is large		X		

Regarding the routing method, it can first be concluded that it is affected by the warehouse type and role, order characteristics, and demand profiles. For external pallets, DM engine blocks, and other DM material, the pick lists are so short it is not worth having a complex routing method (Bartholdi & Hackman 2019). For boxes, which have long pick lists, narrow aisles, and frequently picked SKUs spread out along the whole aisles, the transversal routing method is suitable (Bindi et al. 2009; Chan & Chan 2011). It is also an easy routing method for workers to follow and functions well together with the zone and wave picking method. Note that it requires that the WMS system can generate pick lists according to the order in which the SKUs occur horizontally in the aisle. The design decisions on routing method are presented in Table 5.14.

Table 5.14: The suitable routing methods, based on the storage areas' context.

Routing method	**Suitable context**	**External pallets**	**Boxes**	**DM engine blocks**	**Other DM material**
Transversal routing	Long pick lists, and/or narrow aisles		X		
Return routing	The storage allocation method is based on picking frequency				
Midpoint routing	Relatively short pick lists and the WMS can support the method				
Largest gap	Relatively short pick lists and the WMS can support the method (even more complex than midpoint)				
No routing method at all	Very short pick lists, pick lists contain picks all over the warehouse, and/or the WMS can not support a routing method	X		X	X

Chapter 6

Recommendation

This chapter fulfills the second research objective and the purpose of the thesis by recommending a configuration of Scania's pre-assembly warehouse for when the phaseout of the DL engine has been realized, considering the warehouse context. The chapter includes sections about how the final recommendation is developed, its practical applicability, and its risks and sensitivities. The chapter is concluded with a summary of the recommendation, including comments on what it requires from the WMS.

6.1 Developing the Recommendation

Having decided on the most suitable configuration element options for each storage area, the next step is to develop the final recommendation by combining these and placing all storage areas inside the warehouse. When doing this, certain compromises might have to be made to make the recommendation realizable. As stated in the introduction, a challenge is often to decide between many feasible designs (Dissanayake & Rupasinghe 2021; Rouwenhorst et al. 2000). Therefore, in this case, the recommendation is considered finalized when it meets the validation criteria mentioned in the frame of reference chapter, which are: (1) capacity need is met; (2) suitable configuration element options are possible to use; (3) travel distances are reduced, and; (4) congestion risk is low. Criteria (1) is essential to meet the business requirements, and according to Faber et al. (2017) and Kembro and Norrman (2021), criteria (2) can help increase warehouse performance since the configuration is adapted to the context. Regarding criteria (3) and (4), they both increase warehouse efficiency (Bartholdi & Hackman 2019; Bindi et al. 2009; Chao-Hsien Pan & Shih 2008; Zapata-Cortes et al. 2021).

Before placing out the storage areas, the non-negotiable areas in the warehouse must be taken into consideration since the square meters for these areas can not be used for storage. The non-negotiable areas are the handover areas for V8 and PS, pedestrian aisles along the walls, and the mezzanine floor in the northwest part of the warehouse that limits the space available for storage there. The non-negotiable areas can be seen in Figure 6.1.

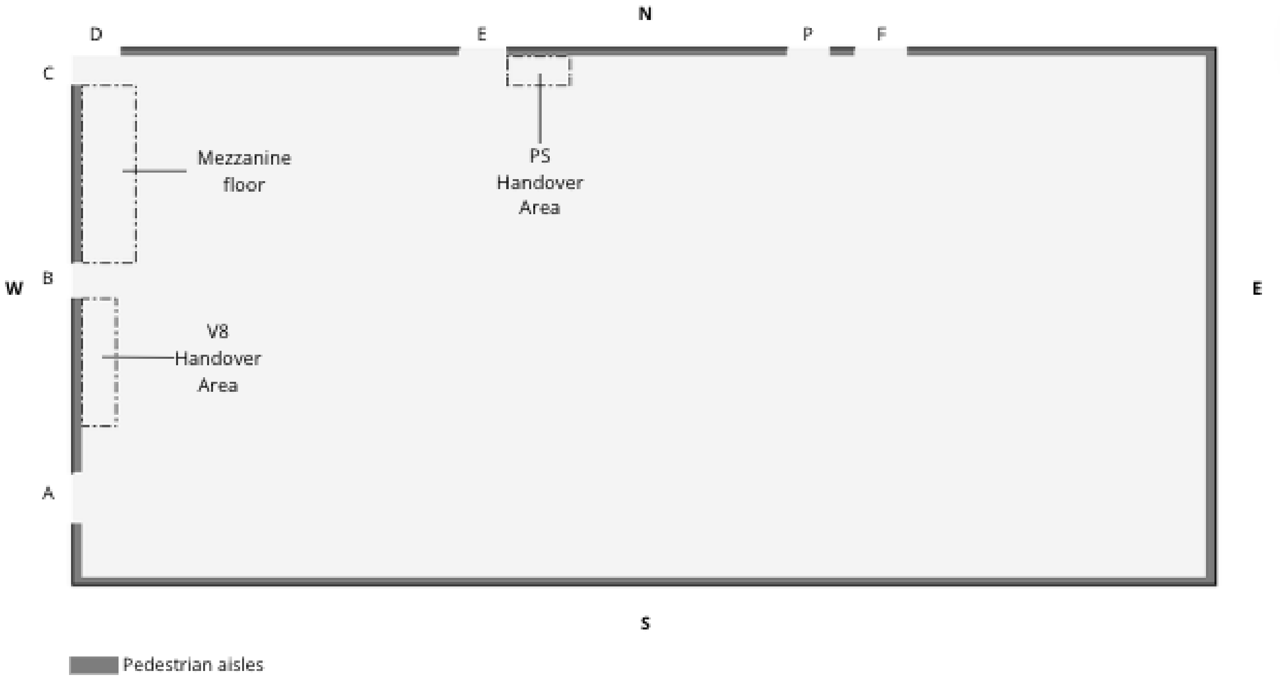


Figure 6.1: The warehouse facility with the non-negotiable areas placed out.

Now, the storage areas can be assigned their own space in the warehouse. Giving the storage areas a suitable placement is prioritized over giving the so-called other areas such as coffee areas, truck parking stations, and so on, a good placement. This is because the storage areas are more value-adding and since the design of the other areas is out of scope as long as there is space left for them somewhere in the warehouse. Iterations are made to find a placement of the storage areas which fulfill the validation criteria. Some key parts of the process are described below.

From the maps of the inbound and outbound flows, see Figure 4.6 and Figure 4.7 in the empirical findings chapter, it becomes evident that the storage areas for external pallets, boxes, DM engine blocks, and other DM material compete with each other in terms of getting positioned in the west part of the building. Due to the set position of the inbound and outbound gates, the east corner of the warehouse is unfavorable for all storage areas from a travel distance and material flow point of view.

According to Table 5.8 and Table 5.9 in the analysis chapter, the external pallet storage area has the most inbound and outbound travel. To minimize total travel distance in the warehouse, it might therefore seem reasonable to give this storage area the most favorable location. However, it is the largest storage area, which means that if it gets its desired location and aisle direction, it occupies the whole west part of the building. This would mean that the boxes, and particularly the DM engine blocks and other DM material, get longer travel distances. Nonetheless, with the external pallet storage area placed in its most favorable location, the box storage area is placed in its "next best" location which is as close as possible to gate A, with aisles parallel to the west wall to align with its inbound material flow. The DM engine blocks and other DM material are placed in the north part of the building to avoid increasing the travel distances for these storage areas unnecessarily. This layout is called alternative one, and the layout looks as in Figure 6.2.

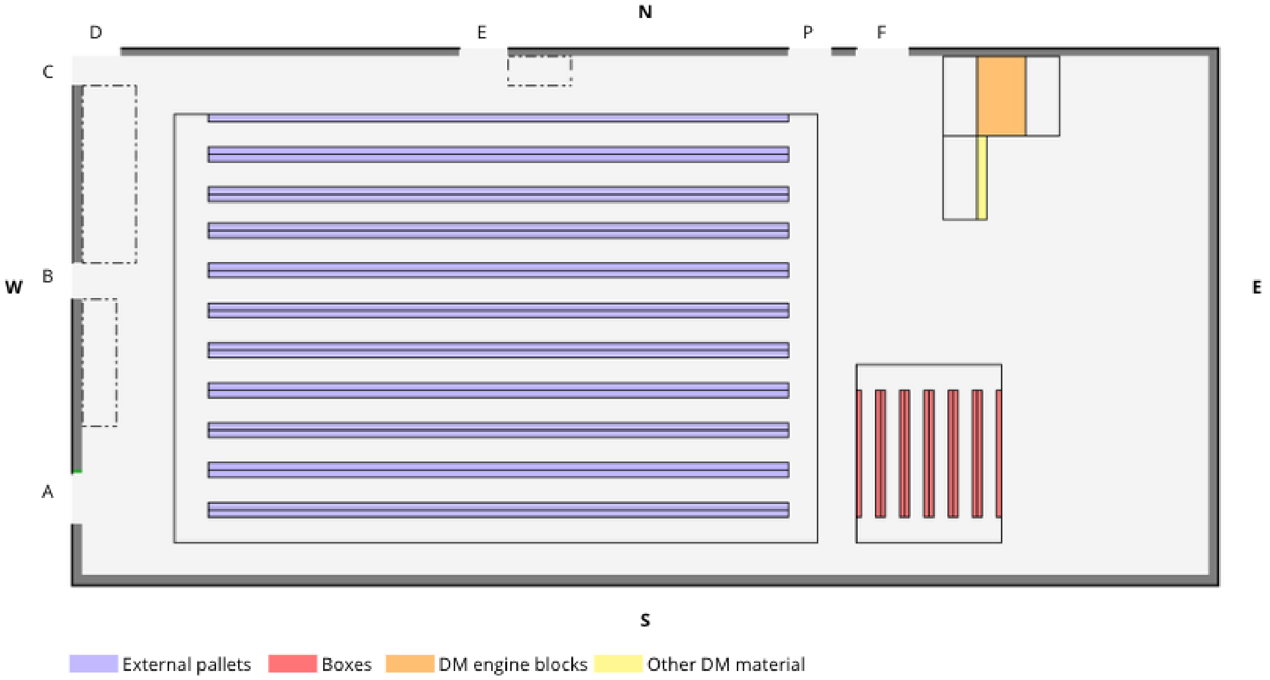


Figure 6.2: Placement of the main storage areas, alternative one.

The placement of storage areas in alternative one means that the box flow does not interfere with the external pallet flow, and the configuration element options chosen for the box storage area in the analysis can be used. With this in mind, the box storage area's placement in alternative one seems attractive. The placement of DM engine blocks and other DM material, however, is poor. Their travel distances are unnecessarily long since the SKUs enter the west part of the building from gates D and E, have to travel far to the east to be stored, and then back west again for outbound delivery through gates A, B, and C. Also, this placement of DM engine blocks makes it harder to perform put away and picking from different sides which, in turn, makes it more difficult to enable deep lane floor storage with FIFO.

If an adjustment is made by moving the DM engine blocks and other DM material to their optimal locations, the total distance traveled inbound and outbound for these storage areas would decrease significantly. The exact decrease per inbound and outbound travel would together be 126 meters for DW DM engine blocks, 130 meters for V8 DM engine blocks, 164 meters for DW other DM material, and 143 meters for V8 other DM material. Considering the number of inbound and outbound travels made per day for these SKUs, see previously presented Table 4.6 in empirical findings, this change would lead to a decrease in travel distance of about 27 kilometers per day, compared to their placement in alternative one. Furthermore, this change would enable both DM engine blocks and other DM material to be placed in their natural material flow, and allow for putting away DM engine blocks from the side closest to inbound and picking them from the side closest to outbound.

The compromise with such an adjustment is that an extra rack would have to be added in the south-most part of the external pallet storage area and parts of the northeast section of the external pallet storage area would have to be moved to the east side of the warehouse, compared to alternative one. However, if the PS SKUs were to be put in the racks moved to the east, the distance to their inbound gate F and outbound gate E would be unaffected, which would mean that the total travel distance for the external pallet storage area would remain the same as in alternative one by doing only this change. Having PS external pallets separated from the other external pallets is considered feasible since they should be in separate aisles anyway, and PS becomes a natural zone in the zone picking strategy. With this placement of PS, both put away and picks are made from and to the west part of the rack, so the most frequently picked PS SKUs should be placed in the west part of their racks to decrease travel distances. With this compromise, the travel distances for DW and V8 external pallets would increase with the most south rack, but just with a few meters. The new layout suggestion is called alternative two and can be seen in Figure 6.3. In total, the travel distance in the warehouse is decreased with alternative two compared to the alternative one.

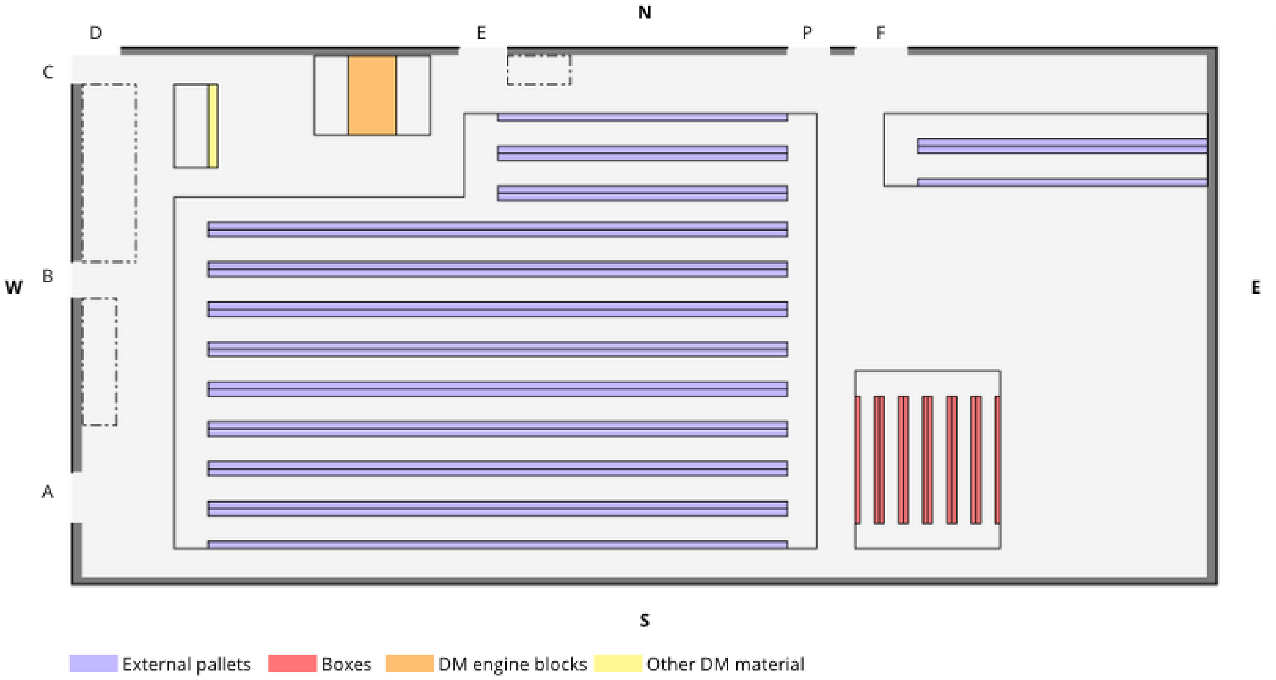


Figure 6.3: Placement of the main storage areas, alternative two.

With alternative two, the DM engine blocks, other DM material, and external pallets, which all have more travel than the box storage area, are positioned in what can be considered prime locations. The location of the box storage area in the alternative is also fine, and therefore alternative two is considered a suitable solution from the perspective of minimizing the total travel distance in the warehouse. Moreover, this layout allows V8 external pallets to be placed in their prime location, which is in the middle of the external pallet storage area at the same height as the V8 handover area. This minimizes the distance traveled for putting away and picking V8 external pallets. Figure 6.4 shows the locations of the DW, V8, and PS racks in the external pallet storage area.

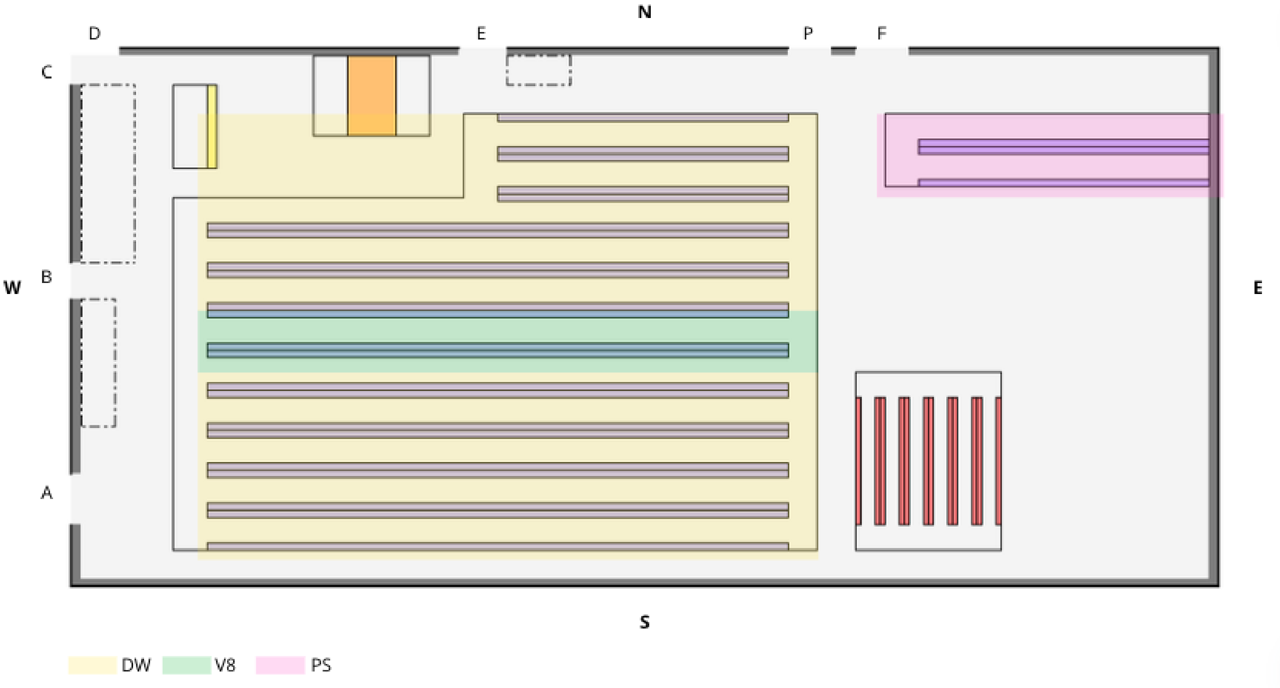


Figure 6.4: The suggested placement of the DW, V8, and PS racks in the external pallet storage area.

From here, the less prioritized carton storage area, piece storage area, and other areas, are placed in the warehouse. The workstation for the receiving area is placed close to the receiving area. The carton and piece storage areas are placed close to the pallet and box storage areas from where they are replenished, and the working area for carton and piece picking is placed in proximity to the carton and piece storage areas. This minimizes the distance traveled in these areas. The sorting areas for boxes and external pallets are placed right by their respective area, also with the motivation to reduce travel distances. Furthermore, the DW trains are placed in proximity to the DW racks in the external pallet storage area. The rest of the other areas are placed out where there is unutilized floor space. The result of these placements can be seen in Figure 6.5.

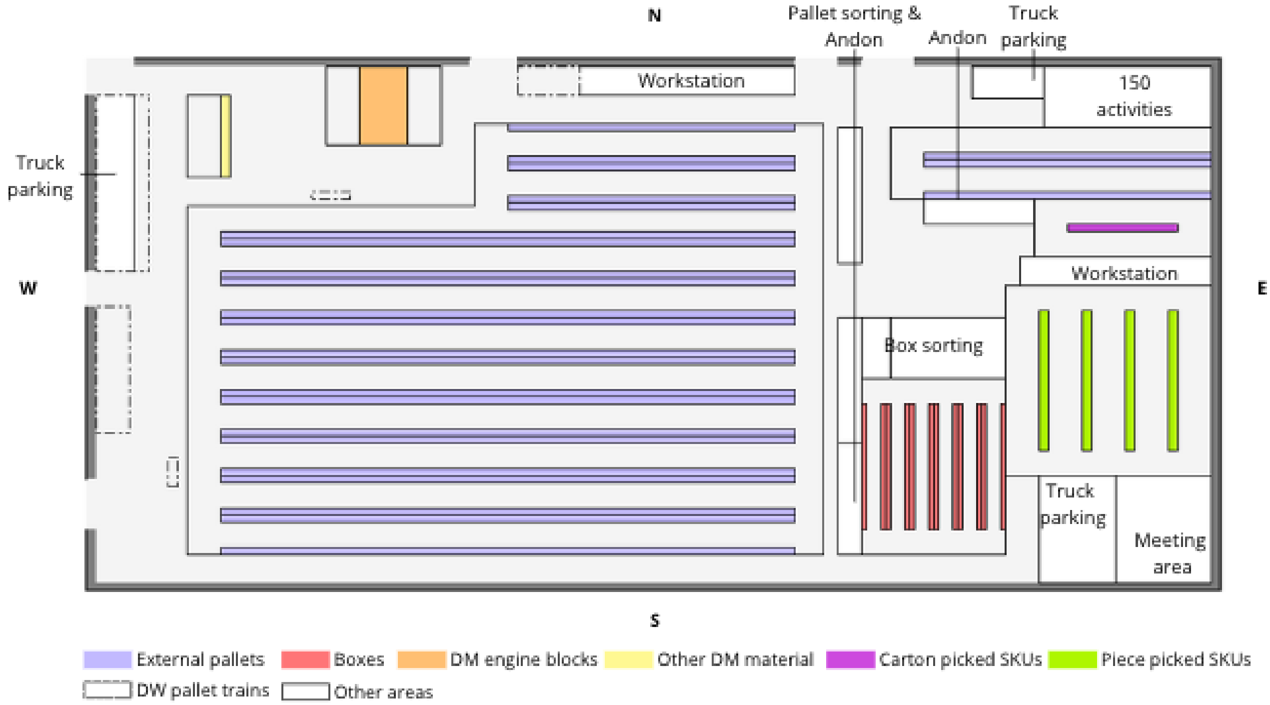


Figure 6.5: The suggested layout, including the placement of so-called other areas.

With the above presented layout, the validation criteria (1) and (3) are met: the capacity need is met and the design does not lead to unnecessary long travels. Noteworthy is that all areas fit without creating a narrow aisle part of the external pallet storage area. However, the general aisle width in the pallet storage area must be kept to the minimum two-way aisle width of three and a half meters for all storage locations to fit, and there is no room for doing a cross-aisle configuration of aisles.

To evaluate the congestion risk and ensure that the configuration is efficient, two types of heat maps are created. Figure 6.6 represents the flows between the inbound gates and the storage areas, as well as between the storage areas and the outbound gates. The lines are color-coded according to the number of travels made per hour. The travels made per hour are derived by adding the travels per day inbound and outbound and dividing the number by the 16 working hours. Since the empirical findings show that inbound and outbound deliveries are quite evenly distributed throughout the day, the average is deemed representative, however, it should be kept in mind that peaks may occur. Green lines indicate that less than ten travels are made per hour, yellow indicates ten to 20 travels per hour, orange indicates 20 to 30 travels per hour, and red indicates more than 30 travels per hour. The grey lines are flows where the number of travels is unknown due to a lack of data.

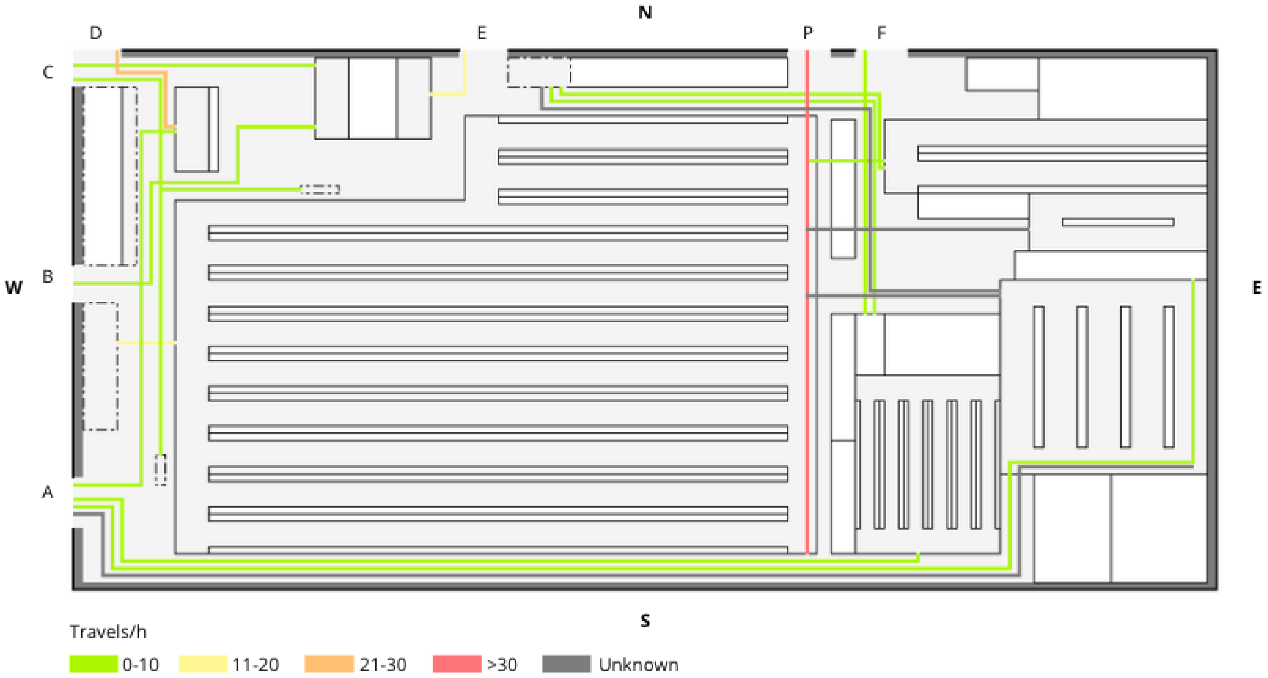


Figure 6.6: Heat map of the flows between inbound gates and storage areas, as well as between storage areas and outbound gates.

The flow heat map shows no evident sign of congestion risk. The only red flow is where the external pallets flow in, which does have many travels but at least is disturbed minimally by other flows with this configuration. Some flows cross each other, particularly in the northeast part of the warehouse and in the northwest corner. However, this is not considered an issue since the flows are green. In the northwest corner, the issue is that the DW train is disturbing the flows for other DM material, V8 DM engine blocks, and V8 external pallets, but below six trains depart every hour, so the interference is still low. Regarding the northeast corner where the flows to the box, carton, piece, and to and from the PS external pallet storage area meet, in total around eleven travels take place an hour, so the risk of these travels happening at the same time and disturbing each other is not significant either. In addition, the outbound flows for boxes, cartons, and pieces have their own aisle in the south part of the building leading to the engine assembly, and an aisle leading to the PS handover area in the north part of the building. This enables these flows to also interfere minimally with the other flows.

Figure 6.7 represents the activities in the storage areas. The map is based on the picks made per day per storage area and customer, according to the previously presented Table 4.6 in the empirical findings chapter. For all storage areas, the activities per day are calculated by multiplying the picks per day by two, since an assumption is made that one put away is made for each pick. The activities per day are translated into activities per hour since the picks are quite evenly distributed throughout the day.

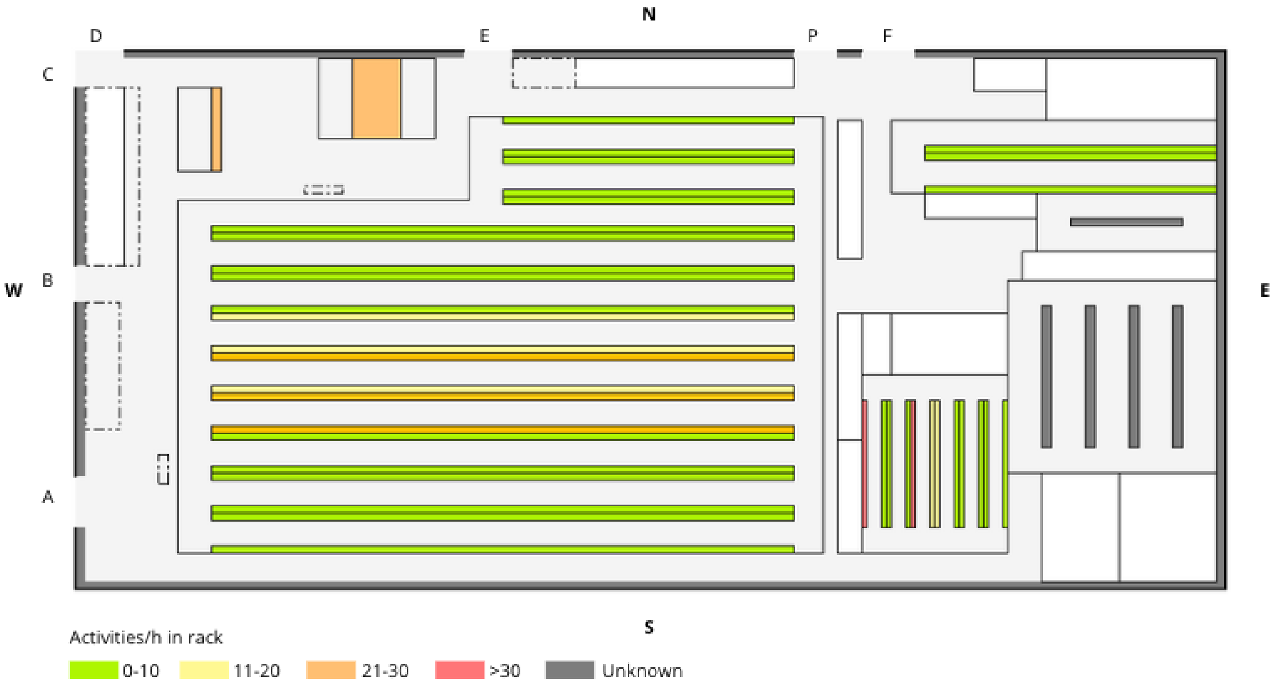


Figure 6.7: Heat map of hourly activities (put aways and picks) in the storage areas.

The above heat map indicates some congestion risks. In the external pallet storage area, the aisles with V8 pallet racks, both full and half pallets, and the DW half pallet racks risk getting congested, the most activities being 45 per hour in a single aisle. On average in these aisles, however, an operator makes three picks or put aways in the same travel, which equals 15 trips per hour, or one every four minutes. Therefore, the risk of many people having to move in the same aisle simultaneously is quite low, although the number of activities is quite high.

Furthermore, the chosen zone picking method and the random storage allocation method help counter the congestion risk in these pallet rack aisles (Bartholdi & Hackman 2019; Gu et al. 2010; Koefler et al. 2011; Manzini 2012; Peterson & Aase 2004). In addition, the placement of the pallet sorting area enables SKUs to be buffered just outside the aisles so that put away operations can wait during peak times of the day when the picking activity is particularly high. This spreads out the activities per day and ensures that picking is not de-prioritized. The backside of this is double handling, since the put away operator would pick up the SKU in the pallet roll rack, place it in the buffer zone, and then pick it up again later, instead of driving straight from the pallet roll rack to put the pallet away. Therefore, the buffer should only be used when necessary. Nonetheless, with this in mind, the congestion risk in the external pallet storage area is not considered critical. Moreover, as stated in the analysis, the congestion risk can be further decreased by giving the two high-activity aisles extra width. However, in this case, it is challenging to find the space to realize wider aisles, why it is not part of the final recommendation.

By looking at the heat map of activities, it can also be concluded that narrow aisles are not suitable in the external pallet storage area. Even though many picks are made every day in the area, they are spread out over many aisles since many SKUs are stored in the area. On average, there are only five travels per aisle per hour. To not let operators spend a lot of expensive time waiting, all operators must work in several aisles. With operators working in several aisles, narrow aisles are not suitable since the turret truck for narrow aisles only performs well when moving in the guiding device within an aisle (Bartholdi & Hackman 2019).

Moving on to the box storage area, two racks are red since they have 36 activities per hour each. The most congested aisle in the box storage area has 54 activities per hour. Since on average 15 put aways or picks are made in the same journey, the average number of journeys in the aisle is four per hour. A measure to decrease the congestion risk and waiting time in this storage area is to choose wave picking over zone picking as the picking method. Since the aisles are narrow, put away can not smoothly be performed at the same time as picking, in the same aisle. With wave picking, this issue is avoided since picking is made according to a schedule, which ensures that picking is not made in all aisles at all times, thereby enabling put away to take place.

Regarding the storage area for other DM material, it is orange with 21 activities per hour. If the vertical CBS storage allocation method suggested in the analysis is followed, the average activity per aisle location is only two per hour, so it is not expected that operators need to wait much for each other. The DM engine block storage area is also orange with its 24 activities per hour, but since put aways and picks are made from different sides, congestion issues are not expected to be a problem in this storage area. By that, validation criterion (4) is met: congestion risk is low.

Regarding the last validation criterion, criterion (2), which states that suitable configuration element options are possible to use, it is also met if the warehouse layout looks as in alternative two. This means that the recommendation meets all four validation criteria, and thereby is finalized. Important to note is that there possibly are other placements of the storage areas resulting in a configuration that also meets all four validation criteria. However, since the proposed configuration is developed based on matching the context for each storage area to the best configuration element options suggested by theory, this configuration is expected to give performance advantages.

6.2 Applicability of the Recommendation

By meeting the four validation criteria, the configuration is expected to perform well, according to theory. However, there is generally a gap between theory and practice (Albert et al. 2023), and the recommendation is therefore demonstrated and evaluated with Scania. During this session, Scania concludes that the recommendation seems practically feasible. Nevertheless, they suggest a few adjustments. For example, the external pallet racks for the customer PS need to move out from the wall so that trucks can make picks from the storage locations closest to the wall. This issue was not captured when collecting requirements or empirical data, highlighting the challenge of capturing all relevant inputs to get a comprehensive understanding of the warehouse context. By removing three and a half meters of each PS rack closest to the wall, many storage locations disappear. This means that the first validation criterion, meeting the capacity need, is no longer fulfilled. Therefore, another rack for PS external pallets, ten and a half meters long, is added next to the rack storing carton picked SKUs. By ensuring three and a half meters of aisle between the two, the operations between the PS external pallets and the carton picked SKUs do not interfere with each other. The updated layout can be seen in Figure 6.8.

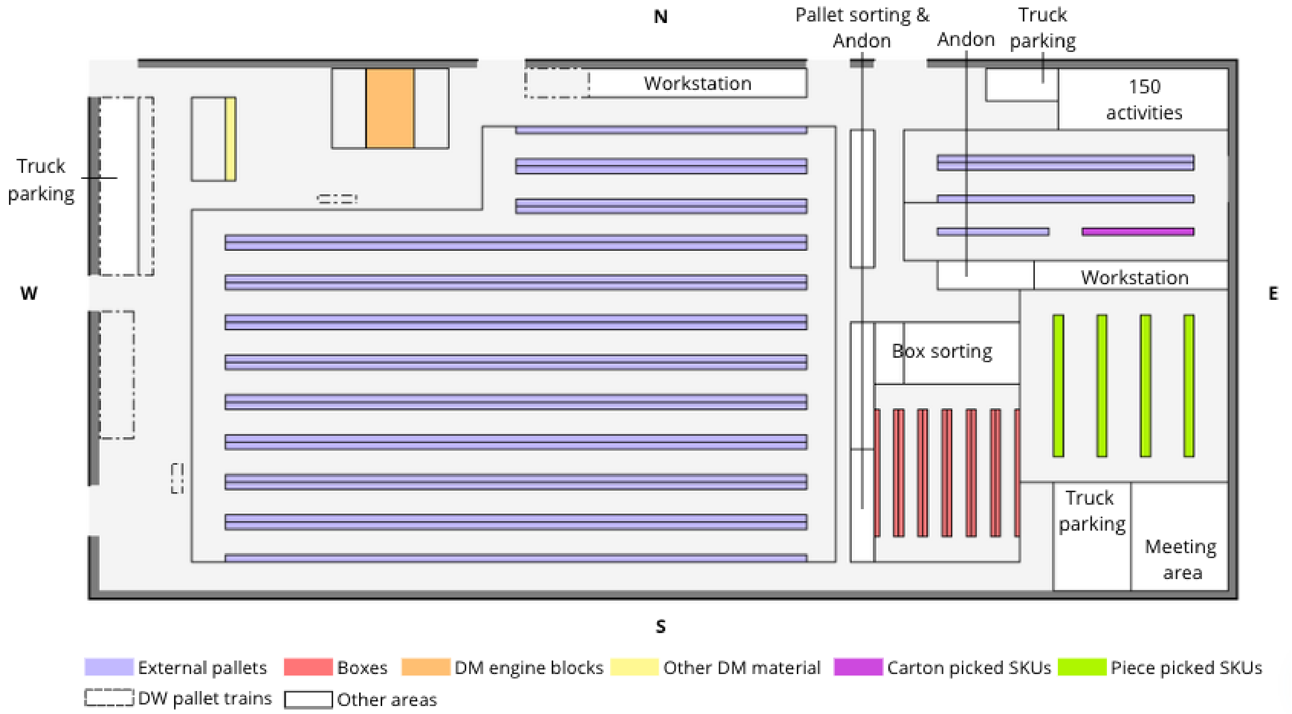


Figure 6.8: The recommended layout of the reconfigured warehouse.

Furthermore, Scania highlights congestion as a risk with the recommendation. They believe that congestion will occur by gates P and F with this layout, despite the flow heat map indicating a low average number of travels per day in the area, suggesting no congestion issues. Scania says that this is because, in reality, more flows are occurring than captured in the data. Such flows can be people traveling to and from the andon areas and truck parking areas. Furthermore, the data analysis does not consider that truck drivers need to turn, might drop a unit load which prolongs their travel, and so on. Scania also highlights the risk of congestion in the aisle between the external pallet storage area and its sorting area, where all external pallets flow in. It is four and a half meters wide, which might not be enough considering that there is movement both from north to south and from east to west. Since there is a discrepancy between theory and practice, a simulation model could be valuable to assess whether the theory underestimates the congestion risk or if the raised gut feeling based on experience overestimates it. This simulation would help decide whether it is valuable to update the layout to reduce congestion or not. However, since there is not much space left in the warehouse in the recommendation, such an update may require other compromises, such as narrowing aisles in the external pallet storage area or relocating other areas, possibly leading to longer travel distances.

Besides the risks highlighted by Scania, other risks might also affect the realizability and the performance of the recommended configuration. One such risk is that the placement of the other areas hinders efficient warehouse operation. For example, the activities in the other area "150 activities" in the northeast corner are unknown. Many activities in this area might lead to even more congestion in the already high-activity inbound area for external pallets and boxes. Another example is the meeting area. Perhaps, its placement just by the storage areas makes the meeting areas very noisy, reducing the pleasantness of the working environment. Also, the employees working in the storage areas for DM engine blocks and other DM material have a long travel to get to the meeting area, which may require longer breaks to be scheduled, perhaps decreasing warehouse efficiency. A potential mitigation to this risk is to divide the meeting area into many small meeting areas spread out over the warehouse. Another example of a potentially flawed position of other areas is that to fit all truck parking areas, one of the areas was made so that trucks are stored double-deep. Like in a double-deep storage area, this may lead to double handling if the same trucks are not stored in depth. Overall, it was not in scope to investigate the context or decide on the optimal placement of the other areas, however, their influence on the rest of the warehouse design, resources, and operations should be investigated before realizing the reconfiguration.

Another risk with the recommendation is that the carton and piece storage areas are not reconfigured in the recommendation, or prioritized when placing the storage areas in the warehouse. Perhaps the carton storage area has more travel than, for example, the box storage area and therefore should have a more favorable placement than it is given in the recommendation. Or, perhaps the inbound and outbound travels are so many to and from the carton and piece storage areas that including them in the heat maps would indicate even more congestion risk in the east part of the warehouse, which could require a change to the recommendation. For instance, a potential change could be to increase the carton and piece storage areas so that they can store all their SKUs themselves and not have to be replenished from the pallet and box storage area. This would eliminate the travel between the external pallet and box storage areas to these storage areas, as well as decrease the size of the external pallet and box storage areas, which could make the warehouse more efficient and less congested. As soon as it is available, data on the carton and piece storage areas should be added to the analysis and recommendation, to develop an even more solid configuration.

6.3 Sensitivity of the Recommendation

Since the recommendation is based on the warehouse context, a major risk is incorrect identification of the context or changes to the context. Below, the sensitivities with the recommendation are discussed for each contextual factor.

6.3.1 Warehouse Type and Role

Starting with the warehouse type and role, changes in this contextual factor would affect the recommendations on the overall operations. For instance, if the other area "150 activities" is moved to the engine assembly, which owns the activities in that area today, 150 square meters are freed up in the warehouse. This freed-up space enables making wider aisles in all congested areas, which could make the warehouse more efficient. If the strategy changes so that the warehouse is required to store the extra safety buffer stock, the external pallet storage area must be reconfigured into a narrow aisle storage area, to fit the extra storage locations needed. With narrow aisles, other equipment is needed, and the picking strategy might need to be changed from zone to wave with a schedule of when picking and put away is performed.

Moreover, the estimated future capacity need is a highly sensitive factor in the recommendation, since it determines how many storage locations are needed per storage area. Two of the most important variables in the capacity calculations are the fill rate and coverage time, which are both decided by central Scania teams. The warehouse capacity need is based on assumptions that the coverage time and fill rate will be the same in 20YY, however, this might not be the case by the time of the reconfiguration. If the capacity need is larger than estimated, for example if the coverage times are increased, more storage locations than included in the recommendation are needed. This would require changes to the warehouse configuration, for instance by removing some areas that are not storage areas from the warehouse or making the aisles in the external pallet storage area narrow. On the other hand, decisions to increase the fill rate or decrease the coverage times would reduce the capacity need. This could partially resolve congestion issues and enable the warehouse to operate more efficiently.

6.3.2 Product Characteristics

Moving on to product characteristics, the introduction of new items and their unit load is a sensitive parameter to highlight. There is a risk that some introductions have a certain unit load currently registered in the system, but that it will be updated by the time of the actual introduction. This could mean that an introduction is estimated to require 20 pallet locations, while in reality, it will require 40 box locations. If this happens for multiple new items, the total space needed for the different storage areas would decrease or increase. Either way, this would require changes to the recommendation.

Furthermore, an updated packaging pool in the warehouse would change the product characteristics of the warehouse by affecting the SKU size, SKU weight, and overall SKU dimensions of each storage area. This would influence the space and equipment needed in the warehouse. For instance, if all standard pallet bases get thicker by ten centimeters, the racking systems storing pallets would have to be reconfigured so that all levels increase by ten centimeters in height. This would reduce the number of storage locations in the racks and thereby require more, or longer, racks in the external pallet storage area to provide the same number of storage locations as the final recommendation. However, the recommended configuration is flexible and likely realizable even if the product characteristics change. This is because, for pallets, the suggestion is only to divide the pallets into full and half pallets, and allocate the tallest SKUs to specific shelves. The required rack length would not change drastically if the SKU size changed, compared to if the shelves were optimized precisely for each SKU size.

6.3.3 Order Characteristics

For order characteristics, a change in the structure of how orders arrive to the warehouse would affect the picking strategy. For example, if the engine assembly starts placing orders the day before they are needed, the pick lists could be prepared so that they always contain SKUs located very close to each other, increasing the picking efficiency. However, a change in order characteristics would not change the pick list length, since it is limited by the number of SKUs that can be stacked or the number of SKUs that fit in the box platforms.

6.3.4 Customer Characteristics

When it comes to customer characteristics, the number of customers and their requirements are very sensitive parameters that affect the warehouse configuration recommendation. For instance, if the phase-out of the DL engine is not realized in the planned time frame, and the warehouse must account for some DL SKUs, each storage area needs more storage locations which would most likely not be feasible, due to the limited space in the warehouse. To potentially be able to handle this, the coverage time or fill rate would have to be changed, or drastic reconfigurations would have to be made which likely would affect the operational efficiency of the warehouse, or result in not all validation criteria being met. Another risk is the introduction of new customers, for instance in the form of additional delivery addresses on the assembly lines. This would affect the configuration of the box storage area since these new customers would need their own racks and aisles.

Furthermore, if one or multiple customers change their requirements on outbound deliveries, for instance in terms of where orders to the different customers are delivered, it would affect the warehouse configuration recommendation. For instance, if the V8 handover area is moved, the position of the V8 racks in the external pallet storage area will no longer be suitable, and they will have to be moved. If the boxes must be delivered through another gate than today, another position of that storage area would likely be more suitable.

6.3.5 Demand Profile

The last contextual factor is the demand profile. The recommendation is based on the assumption that the demand profile has the same characteristics as in 2024. If this changes, this might affect what storage allocation methods are the most suitable. For example, if a few engine variants become very popular, more picks would be made of a few SKUs, leading to a more skewed picking frequency curve, and by that, it would likely be suitable to apply CBS. If CBS is applied, the activity intensity in the warehouse would change, which would affect the congestion and require a broadening of aisles.

To sum up, the final recommendation is very sensitive to changes in the context. In particular, the warehouse type and role and customer characteristics, which affect the capacity need, have a high impact on the recommendation. Changes in the context should be closely monitored by Scania, and if changed, the analysis and recommendation should be updated accordingly, with the help of the analytical framework. By incorporating the new context and redoing the analysis, which is relatively straightforward with the analytical framework, the artefact can be updated to better suit the actual warehouse context.

6.4 Summary of the Recommendation

In Figure 6.9, a high level map of the final warehouse as a whole is illustrated.

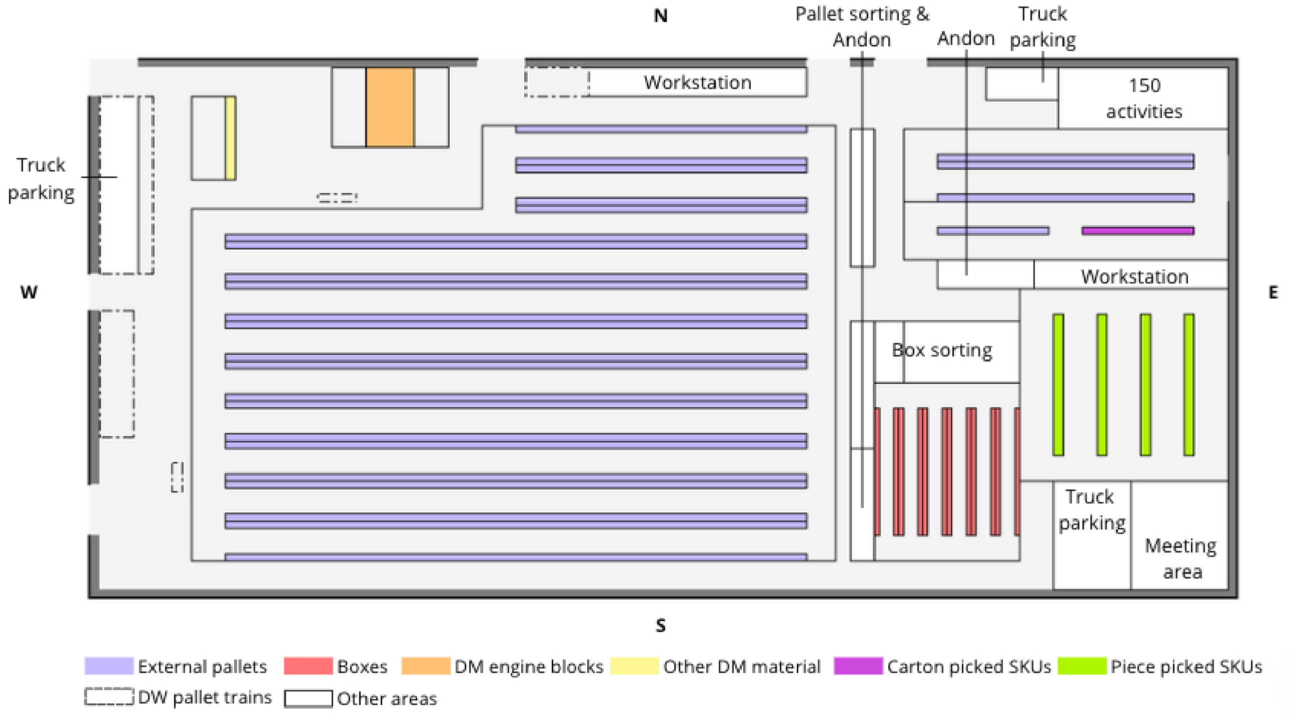


Figure 6.9: The recommended layout of the reconfigured warehouse.

In Table 6.1, Table 6.2, Table 6.3, and Table 6.4, the decisions made on the relevant configuration elements based on each storage area's context are presented.

Table 6.1: The suitable configuration for the external pallet storage area, based on the storage area's context.

External pallets	
Configuration element	**Choice based on context**
Aisle configuration	Parallel aisles
Aisle direction	Parallel to the north wall
Space saving measure	Racking
Aisle width	Two-way
Storing equipment	Single-deep racks. For DW and V8, 17 racks that are 60 meters long and 5 racks that are 30 meters long. For PS, three racks that are 26.5 meters long, and one rack that is 10.5 meters long. Each aisle is dedicated to only half pallet racks or only full pallet racks.
Handling equipment	Reach truck
Storage allocation method	Storage based on the SKU attributes Customer, Weight, Unit cost, and Dimensions + CBS for PS and Random for DW and V8
Picking strategy	Parallel picking
Picking method	Zone picking
Routing method	None

Table 6.2: The suitable configuration for the box storage area, based on the storage area's context.

Boxes	
Configuration element	**Choice based on context**
Aisle configuration	Parallel aisles
Aisle direction	Parallel to the west wall
Space saving measure	Racking
Aisle width	Narrow
Storing equipment	Single-deep racks. 12 racks in total, all 17.5 meters long
Handling equipment	Narrow aisle truck
Storage allocation method	Storage based on the SKU attribute Customer + Random storage
Picking strategy	Serial picking
Picking method	Wave picking
Routing method	Transversal

Table 6.3: The suitable configuration for the DM engine blocks, based on the storage area's context.

DM engine blocks	
Configuration element	**Choice based on context**
Aisle configuration	Parallel aisles
Aisle direction	Parallel to the north wall
Space saving measure	Deep lanes
Aisle width	Two-way
Storing equipment	None. Stored straight on the floor in an area of about 55 square meters
Handling equipment	Counterbalance truck
Storage allocation method	Dedicated storage
Picking strategy	Parallel picking
Picking method	Batch picking
Routing method	None

Table 6.4: The suitable configuration for the other DM material storage area, based on the storage area's context.

Other DM material	
Configuration element	**Choice based on context**
Aisle configuration	Parallel aisles
Aisle direction	Parallel to the west wall
Space saving measure	Racking
Aisle width	Two-way
Storing equipment	Single-deep rack. In total one rack of 11.5 meters, five shelves high
Handling equipment	Counterbalance truck
Storage allocation method	Storage based on the SKU attribute Customer + CBS
Picking strategy	Parallel picking
Picking method	Batch picking
Routing method	None

As a last note in this chapter, it has been stated in the introduction of the thesis that the information system in use by the time of the reconfiguration is expected to have all the capabilities needed to enable the reconfiguration recommendation. For this to be true, the WMS needs to be able to handle multiple classification levels within each storage area, to allow for the suggested storage allocation methods. In practice, this would for example mean that the WMS must be able to separate DW external half pallets from DW external full pallets, as well as DW external half pallets from V8 external half pallets. Furthermore, the WMS needs to be able to generate pick lists with a sequence of pick lines that minimize travel distances. In practice, this would mean that as few aisles as possible are visited during the completion of one pick list, and no operator needs to reverse with the truck inside an aisle.

Chapter 7

Conclusions

This chapter concludes the thesis. First, the fulfillment of the thesis' purpose and objectives is described. Second, the limitations of the research are stated. Third, potential future research is discussed. Fourth and last, the chapter, and thereby the thesis, is finalized by explaining how the research has contributed to the academic sector and to practice.

7.1 Fulfilling the Purpose

The purpose of this thesis was to provide Scania with a configuration of their pre-assembly warehouse suitable for when the phaseout of the DL engine has been realized, based on the warehouse context. The recommendation was based on warehousing theory and aimed to achieve high space utilization as well as operational efficiency. The design science research strategy was employed to fulfill the purpose, and an analysis of relevant contextual factors was made to determine a suitable configuration based on theory and the specific warehouse context.

The outcome of this thesis was a comprehensive recommendation on the final warehouse configuration, detailing the warehouse design, warehouse resources, and warehouse operations of each storage area based on their context, as well as an integration of the storage areas. In line with contingency theory, this was expected to give the warehouse performance advantages. The proposed configuration met the anticipated capacity needs while minimizing travel distance and congestion risks, thereby supporting efficient operations.

7.2 Addressing the Objectives

There were two research objectives for this thesis and below is a summary of how they were formulated and addressed.

RO1: Identify the warehouse context based on relevant contextual factors, and which configuration element options are most suitable based on this.

To approach the first objective, the process commenced with identifying business requirements and design constraints. These touched on aspects such as warehouse facility limitations and customer delivery requirements. Following this, a literature review was conducted to understand relevant contextual factors, configuration elements, their available options, and the suitable context for each option. The relevant contextual factors were warehouse type and role, product characteristics, order characteristics, customer characteristics, and demand profile. These influenced the configuration elements aisle configuration, aisle direction, aisle width, space saving measures, storing equipment, handling equipment, storage allocation method, picking strategy, picking method, and routing method, each offering distinct options. For example, for picking method, options included single, batch, zone, or wave picking, with selection dependent on the contextual factor order characteristics, particularly the order size.

Data on the case company's warehouse context was collected through interviews, observations, and secondary sources such as information systems. This data was analyzed using pattern matching, to understand the context. A key finding was the significant variation in context across different SKU groups, necessitating separate configurations for each. The groups became four different main storage areas, in the form of external pallets, boxes, DM engine blocks, and other DM material. Decisions on the warehouse configuration were made by matching each storage area's context with the theoretically most suitable configuration element option depending on the context, for each configuration element. For instance, due to the prevalence of numerous small orders for DM engine blocks, a batch picking method was recommended for that storage area.

RO2: Develop a recommendation on how to configure the warehouse given RO1.

After identifying the context and suitable configuration element options for each storage area, the next step involved assembling the artefact; the final configuration recommendation. The final recommendation considered the chosen configuration element options identified in RO1 and placed the storage areas in the warehouse in a way that met the warehouse capacity need, minimized travel distances, and mitigated congestion risk. The final recommendation included suggestions on the overall warehouse layout, as well as the design and resources for each storage area, such as aisle configuration and storing equipment, and guidance on how to perform warehouse operations within each storage area, such as storage allocation method and picking strategy. The final recommendation was summarized in the section 6.4 in the recommendation chapter.

Some insights were gathered during the development of the recommendation and are worth highlighting. For instance, it was recommended to optimize the external pallet storage area by categorizing SKUs based on size, adjusting shelf depth and heights accordingly, and putting taller SKUs on top or floor locations. This approach was projected to accommodate the required capacity without necessitating a transition to narrow aisle storage, thereby enhancing operational efficiency. Moreover, due to the product characteristics, especially SKU weight, and demand profile of DM engine blocks, storing them directly on the floor in designated lanes was proposed to save space and time. To save both space and time, and due to the customer characteristics and demand profile, the boxes, DW external pallets, and V8 external pallets were recommended to be allocated to racks based on what customer they belong to and then randomly within those racks. Additionally, it was concluded that the picking frequency curves for DW external pallets and V8 external pallets were not skewed enough for the CBS allocation method to be valuable. Due to the long pick lists for boxes, the CBS was not expected to be impactful in that storage area either. It was also found that due to the order characteristics and demand profile, wave picking was a suitable picking method for the box storage area and zone picking for the external pallet storage area to make picking efficient and avoid congestion. Furthermore, the order characteristics showed that it was only worth having a routing method in the box storage area, where transversal routing should be applied.

Regarding the placement of the storage areas, it was concluded that the total overall travel distance was decreased if the DM engine blocks and other DM material SKUs are put in the northwest corner of the building. Heat maps indicated that the warehouse was not expected to have critical congestion issues with such a placement. However, Scania highlighted that the congestion risk might be higher in practice than what the maps showed. Therefore, the congestion risk, together with sensitivities relating to changes in the warehouse context, must be monitored until the realization of the warehouse reconfiguration. Nonetheless, Scania's general view is that the recommendation is considered applicable and appropriate.

7.3 Contributions

This thesis contributed to practice by solving challenges for Scania by recommending a future configuration of their engine pre-assembly warehouse in Södertälje, matching the warehouse's expected future context. Except for the recommended configuration, an analytical framework was developed, which could be applied in any warehouse configuration process where the design decisions are based on context. The framework could for example be used by Scania to update the configuration recommendation closer to the realization date, when the context is confirmed and more accurate data is available. It could also be used by another company in another warehouse configuration project.

Moreover, this thesis contributed to the academic sector by first of all adding a DS research study about a configuration of a real-world, heterogeneous pre-assembly warehouse in a manufacturing company. This is in contrast to the many existing articles about the design of distribution warehouses and homogenous warehouses (Albert et al. 2023). According to Albert et al. (2023), the few existing articles about heterogeneous warehouses often focus on one configuration element and miss that improvements in one element can cause problems in others. This thesis helped fill this gap by analyzing and integrating ten configuration elements for four storage areas, which confirmed that compromises needed to be made when these were integrated in a real-world scenario.

The thesis did not reveal any new warehousing theory, however, it confirmed already published literature regarding the importance of considering the context when configuring a warehouse. This thesis explored what configuration elements options were suitable based on context, inspired by the approach by Kembro and Norrman (2021), but did it for a pre-assembly warehouse, in contrast to their omni-channel warehouse perspective. Interestingly, this thesis found that storage areas within the same warehouse might have different contexts and thereby should be configured differently. Similar to Kembro and Norrman (2021), it was found that compromises must be made when developing the configuration, in this case when putting the suitable configuration element options for each storage area together into a physical warehouse with real-world constraints. Further, there is no undisputed way to measure structure and context (Faber et al., 2017). However, this thesis at least found the spiderweb structure for mapping a company's contextual factors, originally done by Kembro and Norrman (2021), to be a useful tool to synthesize the warehouse context. Moreover, this thesis found that there are other factors, independent of the context, that affect warehouse performance, confirming what has been stated by Faber et al. (2017). In this case, it was the business requirements and design constraints on the configuration.

The thesis also confirmed literature's view of companies usually basing warehouse design decisions on rules-of-thumb, rather than theory, and that there is a gap between theory and practice in terms of how to configure warehouses. For example, the recommendation was developed and validated according to theory, which led to the conclusion that there was no critical congestion risk. However, when demonstrating and evaluating the recommendation with the case company, they feared that the congestion risk was high, based on their experience. To help bridge the gap between theory and practice, in line with the request from Albert et al. (2023), this thesis contributed with an analytical framework that helps develop a theoretical and context-based warehouse configuration that is practically applicable and valuable.

7.4 Limitations and Future Research

The thesis was limited by only studying the case of one warehouse in one company, and it was difficult to generalize the findings and output of the project. Therefore, it would be interesting to apply the analytical framework to develop configurations in other warehouses, both within the case company and at other companies. This would reveal if the analytical framework is as useful in the general case as expected, and is suggested as future research.

The realizability of the final warehouse configuration recommendation is limited by the lack of exact data on the future warehouse context. The case company should focus on improving the understanding of the future context and with this, validate the capacity need and redo the pattern matching between context and suitable configuration element options to update the recommendation. Further, it could be investigated what measures should be taken to decrease the congestion in the warehouse, highlighted in the demonstration and evaluation of the artefact. This could include an analysis of whether it is worth making the aisles in the external pallet storage area narrow to free up space in other parts of the warehouse, or if certain areas, such as the carton storage area or other areas, should be moved from the warehouse. Another investigation could be if it is worth moving the inbound doors to the east wall of the facility, to enable other material flow directions. It could also be investigated if the coverage time could be decreased, to decrease the storage capacity need. This could potentially be a suitable new master's thesis subject at Scania and would entail looking into, amongst other factors, demand forecasts, storage costs, and inventory policies. Another limitation that would be interesting to challenge, for example through a future master's thesis, is the possibilities and effects of implementing automation solutions in the warehouse.

Furthermore, the data availability was a limitation that narrowed down the scope of the thesis. A more detailed configuration recommendation, including an analysis of the carton picked SKUs and piece picked SKUs, require more data but would have made the configuration recommendation more complete. It would also prove that the analytical framework is solid enough to handle the full complexity of a heterogenous warehouse, with SKUs ranging from pieces and cartons to pallets and boxes.

Due to the limited project time frame of 20 weeks, the warehouse configuration recommendation did not include a cost estimate or implementation plan. For the warehouse configuration to be realized, such analyses must be made to build a business case for the reconfiguration project. Lastly, because the configuration recommendation is to be realized first in 20YY, the artefact could not be thoroughly tested or evaluated in the thesis. From a DS perspective, it would be interesting to evaluate how well the artefact performs once it is realized, and by that validate the analytical framework on how well it contributes to bridging the gap between warehousing theory and warehousing practice.

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Appendix

A - Interview Guide

Introduction

We are students from LTH, specializing in Supply Chain Management. We are performing our master thesis here at Scania and research how, from a theoretical perspective, the engine pre-assembly warehouse should be designed once the DL engine has been phased out. We are not here to evaluate how you work today, but rather want your input on how the resources, equipment and operations function today and what the requirements on the warehouse in 20YY are. This is very valuable information for us, since it gives us an understanding of the warehouse context, which is the base for the configuration.

(1) What is your role?

Questions to Group leader Logistics development

Understand the problem the artefact is to solve

(1) What is the problem that induced this thesis?

(2) From your end, what do you want this thesis to lead to?

(3) Do you expect this thesis to investigate automation options?

(4) Do you agree with the stated purpose?

(5) Do you agree with the problem formulation?

(6) Do you agree with the research objectives?

(7) Do you agree with the deliverables?

Warehouse type and role

(1) What type of warehouse is this?

(2) What is the role of the warehouse in the supply chain?

(3) Who are the suppliers?

(4) Who are the customers?

(5) What are the goals and service requirements of the warehouse in 20YY?

(6) What products should it store in 20YY?

(7) What is the capacity need in 20YY?

(8) What is the coverage time and why?

(9) What fill rate do you use and why?

(10) During what hours does the warehouse operate today, and what will be changed in 20YY? How many days a week and how many days a year?

Questions to Project manager Engine assembly

Customer characteristics

(1) What are the customer requirements? How and where does the engine assembly expect to receive the material flows?

(2) Does the engine assembly have any other requirements for the warehouse configuration?

(3) How does the engine assembly place orders to the warehouse?

Questions to Project manager DEPA

(1) What is the average rate of introduction of new components, per customer and unit load type?

(2) What is the average phase out of old components, per customer and unit load type?

Questions to Supply chain developer

(1) What is the capacity need in 20YY?

(2) What is the coverage time and why?

(3) What fill rate do you use today and why? Will it remain in 20YY?

Questions to Project manager Logistics

(1) What are the possibilities with the information system? How do you expect it to change until 20YY?

Questions to Logistics developers, Workshop technicians, and Material handlers

Note: All logistics developers, workshop technicians, and material handlers have different responsibilities in the warehouse, some are responsible for receiving, and other people are responsible for put away, storage, picking and shipping for the different types of SKUs. What questions were asked in each interview depended on the role of the interviewee.

Product characteristics

(1) What type of SKUs will the warehouse store in 20YY?

(2) What special handling is required?

(3) Are some SKUs/components fragile, perishable or very valuable?

(4) What is the stackability of SKUs?

Order characteristics

(1) How do you receive the orders?

(2) How do you translate the orders to pick lists?

(3) How many order lines are there per order?

(4) How many SKUs are there per order?

(5) What is the average number of put aways and picks made during the same travel?

Demand profile

(1) Are there any seasonality trends?

(2) Are there any affinity patterns?

Warehouse design and resources

(1) What will the facility look like in 20YY?

(2) What storing equipment do you use?

(3) Per SKU, what margins are needed in the racking systems?

(4) What handling equipment do you use?

(5) What aisle width is needed to operate this equipment?

(6) What other areas, except for storage, do you need in the warehouse 20YY?

Warehouse Operations

(1) What does the inbound process look like today, and what are the requirements on the inbound flows that can not be changed in 20YY?

(2) What is the volume handled inbound?

(3) What does the put away and storage process look like today, and what are the requirements on the put away process that can not be changed in 20YY?

(4) What does the picking process look like today, and what are the requirements on the picking process that can not be changed in 20YY?

(5) What does the outbound process look like today, and what are the requirements on the outbound flows that can not be changed in 20YY?

(6) What is important to consider regarding safety and ergonomics?

(7) Is the work spread out evenly throughout the day?