Warehouse Configuration with Contextual Considerations in a Distribution Centre for Perishable Goods

A design science study of a Swedish distributor in the wholesale sector

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Master Thesis

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Master Thesis in Industrial Engineering and Management

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ABSTRACT

Title	Warehouse Configuration with Contextual Considerations in a Distribution Centre for Perishable Goods: A design science study of a Swedish distributor in the wholesale sector
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Problem Statement	Company Pie is planning for a new centralised distribution centre, as part of a reorganisation of their distribution network. This entails consolidating volumes from several existing facilities, and another company named Company Rho, when setting up a distribution centre configuration. Company Pie wants a second set of eyes to create a configuration, including operations, and design and recourses, for the new distribution centre.
Purpose	The purpose of this thesis is to design a new warehouse configuration for Company Pie's centralised facility for perishable goods, considering accurate contextual factors.
Research Objectives	To fulfil the purpose, the first objective is to describe the current the warehouse configuration of Company Pie's existing warehouses. The second objective is to identify the contextual factors influencing the new distribution centre. The third and final objective is to develop a configuration for the new distribution centre.
Methodology	The study was conducted by following the design science research methodology. Fist, a literature review with three main areas, contextual considerations, warehouse configuration, and perishable goods warehouse was conducted. Then data was collected through interviews, observations, and through data extraction from information systems. The collected data was then analysed to identify configurational elements, which were combined in an artefact of the new distribution centre configuration.
Conclusion	Firstly, the current state of Company Pie was described, arriving at the conclusion that Company Pie and Rho are organisationally similar, and that the new distribution centre is considerably larger than the existing distribution centres. The second objective of identifying contextual factors

revealed that the consolidation of the two companies results in changes in foremost product- and order characteristic, demand profile and assortment. Through analysis this led to the final objective of determining configurational elements. The new distribution centre utilises family grouping to store product and zone picking to perform the picking process.

Keywords Warehousing, Warehouse Configuration, Warehouse Design, Distribution Centre, Contextual factors, Perishable Goods

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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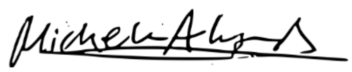
Thank you!



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Emma Holmqvist

Lund, May 2024

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

SKU	Stock Keeping Unit
DS	Design Science
WMS	Warehouse Management System
AGV	Automated Guided Vehicle
FIFO	First In First Out
DC	Distribution Centre
PDC	Company Pie's current main Distribution Centre
RDC	Company Rho's Distribution Centre
NDC	The New Distribution Centre of Company Pie

1 INTRODUCTION

The first chapter in the thesis provides academic background information and introduces the focal company, contributing with a perspective from practice. Thereafter, the chapter addresses the problem at hand, defines the purpose and research objectives, and outlines the scope and delimitations. Finally, the chapter concludes with an overview of the thesis' overall structure.

1.1 Background

Warehousing is integral to business and supply chain strategies, yet it has historically been undervalued, with some even advocating for its elimination (Frazelle, 2016; Gu, et al., 2007). Due to the strong linkage warehousing has to other critical supply chain components, it is essential to consider the broader business context when making key decisions about warehousing facilities (Rushton, et al., 2014; Eriksson, et al., 2019). Frazelle (2016) underscores how warehousing has the potential to add value, facilitate decision-making, and influence customer service. This can be done through shorter response times, value-added services, consolidation, and inventory management, contributing to economies of scale and risk mitigation.

The function of a warehouse can generally be described as a trans-shipment point in a supply chain where goods are received and dispatched as quickly, efficiently, and effectively as possible (Richards, 2018). Distribution centres (DCs) are a common warehouse type characterised by their proximity to the customer base. A DC typically distributes products to regular customers, for example retail stores, and handles large volumes (Bartholdi III & Hackman, 2019).

Introducing warehouses as pivotal units within supply chains, the complexity of creating a well-functioning warehouse configuration becomes apparent. In this thesis warehouse configuration refers to warehouse operations together with warehouse design and resources, in line with Kembro et al. (2018). Over time warehousing activities have become increasingly complex and comprehensive due to changes in the environment, and the perishable food industry is no exception (Frazelle, 2016; Vanickova, 2019). Warehouses must adapt to evolving business landscapes and address growth challenges to maintain efficiency and competitive advantage.

As seen in the thesis title, this project centres around a perishable goods DC. According to Bartholdi III and Hackman (2019), a typical characteristic of a DC handling perishables is that the goods spend a relatively short time in storage. In this thesis, perishable goods refer to goods that have finite or limited shelf life for which both shelf life and quality can be substantially affected by temperature conditions (Aung and Chang, 2023; Nilsson et al., 2009). There is an emphasis on efficiency in the DC due to product shelf life and the high cost of refrigerated areas; furthermore, storage is typically adapted to the First In First Out (FIFO) principle.

To address the significant impact that the surrounding environment has on a business's warehouse, the contingency approach is adapted in this thesis, meaning that relevant contextual factors will be considered. Literature suggests that by adapting the configurational elements in warehouses to suit specific contexts can enhance performance (Kembro & Norrman, 2021; Faber, et al., 2017).

1.2 A Perspective from Practice

The focus company of the thesis, referred to as Company Pie, for anonymization purposes, is a Swedish supplier in the wholesale sector offering dry, cold, and frozen goods. Company Pie operates under the umbrella of a large company group involved in the trade of perishable goods, referred to as Company Group Pie. This affiliation grants Company Pie access to one of Scandinavia's most extensive productions of wholesale ingredients. Additionally, Company Pie collaborates with other internationally renowned producers and holds a prominent position as a large importer of wholesale ingredients in Scandinavia.

Company Pie is currently centralising their supply chain by consolidating multiple warehousing facilities to accommodate for future growth. As a part of this change, they are also transitioning to include more automated elements in the DC operations. These changes affect both Company Pie and another company group entity, referred to as Company Rho. As part of the centralisation process, Company Rho's and Company Pie's DCs will merge into a single, centralised DC. Currently, both companies receive goods from multiple vendors to their various DCs in Sweden.

A simplified version of the current supply chain network of DCs is depicted broadly in Figure 1.1 below. Company Pie operates two DCs, one of which is the primary DC, called PDC. Company Rho operates one DC, named RDC in this thesis. This configuration totals three warehouses, which will be consolidated into one large DC abbreviated as NDC.

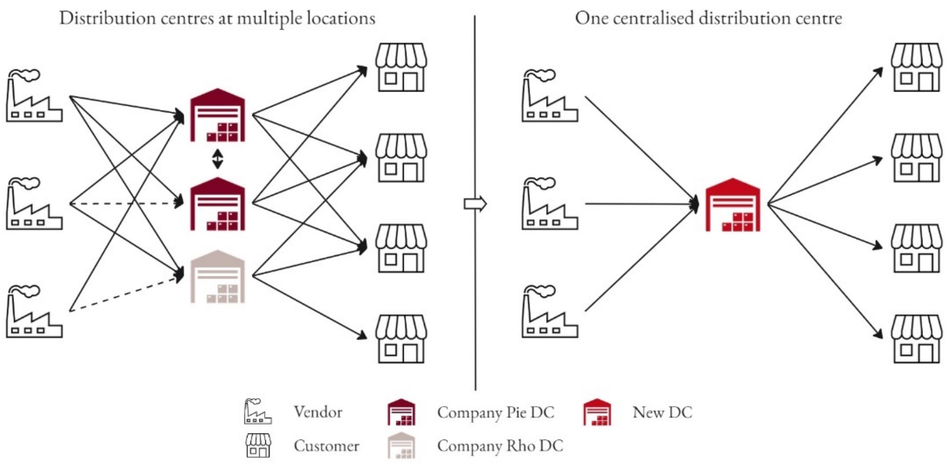


Figure 1.1 Company Pie and Rho are transitioning from a decentralised supply chain with multiple DCs to a centralised supply chain with one DC.

1.3 Problem Statement

As a result of consolidating the DCs, Company Pie is tasked with configuring the new centralised DC for the Company Group Pie. This entails merging volumes from the existing warehouse setup into one facility. The new DC also needs to accommodate future growth, in line with the Company Group Pie business strategy. Since this is an important project for the company, they want a second set of eyes on the problem in hopes of gaining benefits from involving a theoretical perspective.

The aim for Company Pie is to establish efficient operations, design, and resource allocation at the NDC. Moreover, there is an external requirement to incorporate Automated Guided Vehicles (AGV) into the new configuration. Given these factors, it is necessary to develop and design suitable configurational elements for the new DC based on the current warehouse configuration and contextual factors to ensure effective and efficient operations (Kembro & Norrman, 2022). Additionally, due to the company's operations in the wholesale sector, the special environmental requirements of various perishable goods need to be considered (Aung & Chang, 2023).

The problem is rooted in a real-world setting with multiple factors and quite specific circumstances, which affect the new configuration, making it challenging to solely rely on the existing research done in warehousing in the context of configuration design and perishable goods. Additionally, general contextual factors must also be considered (Faber, et al., 2017; Kembro & Norrman, 2021). This thesis aims to bridge the gaps between theory and practice, while increasing the readers knowledge about context and complexity, thereby solving Company Pie's problem statement.

1.4 Purpose and Research Objectives

The purpose of this thesis is to design a new warehouse configuration for Company Pie's centralised facility for perishable goods, considering accurate contextual factors. To achieve this purpose and provide Company Pie with a recommendation, three research objectives have been formulated. View Figure 1.2 for a visualisation of the interconnection between the objective and purpose of the thesis.

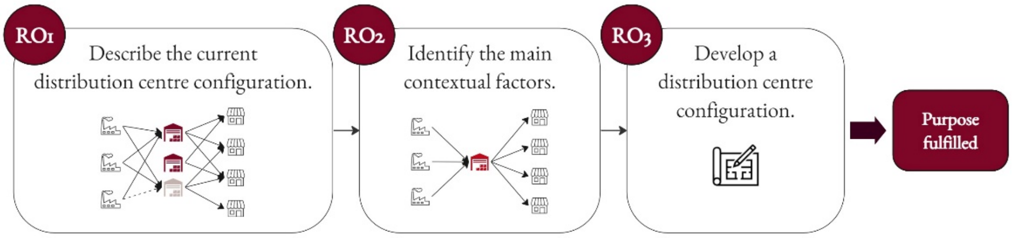


Figure 1.2 A visualisation of the interconnection between the research objectives and purpose of the thesis.

Research Objective 1 (RO1): Describe the Current Distribution Centre Configuration

The first research objective is to describe the warehouse configuration at the PDC and RDC, including operations, design, and recourses. This identifies the preconditions for the NDC, such as existing operational routines and available resources. This objective will be explored through observations, interviews, and data provided by Company Pie.

Research Objective 2 (RO2): Identify the Main Contextual Factors

The second objective is to, through data collection from existing DCs, identify which contextual factors influence the configuration of the NDC. Understanding the contextual factors in the current situation gives insight into which configurational challenges exist in the context and which configurational elements are suitable in the NDC.

Research Objective 3 (RO3): Develop a Distribution Centre Configuration

The final objective is, based on the findings from previous objectives, to develop suitable and satisfactory configuration artefact which includes the predetermined autonomous elements. This will then be presented to Company Pie which fulfils the purpose of the master thesis project.

1.5 Scope and Delimitations

This thesis concentrates on configuring a new DC for storing perishable goods for Company Pie. Figure 1.3 outlines the scope of the project, which encompasses activities solely within the physical boundaries of the DC.

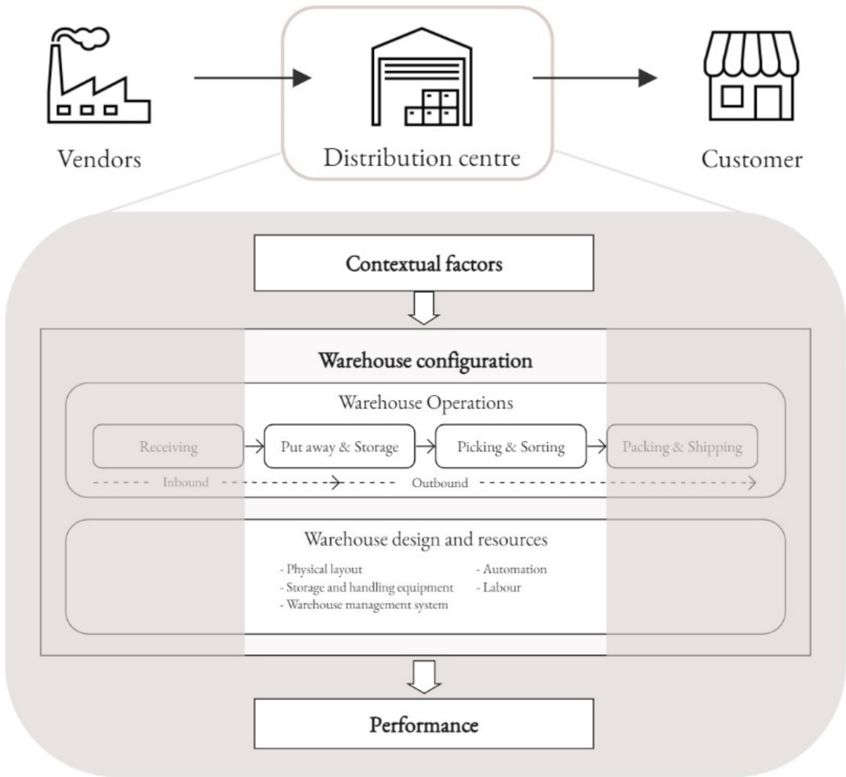


Figure 1.3 An illustration of the thesis scope, with warehouse configuration and contextual factors inspired by Kembro et. al (2018) and Kembro & Norrman (2021).

Activities such as supplier relationships, inventory control, reorder points, and other external factors beyond the walls of the DC will be excluded from consideration. The thesis deliverables will consist of recommendations for DC configuration in the new facility, for the years 2028 and 2034 to account for predicted growth, with accommodations for automated equipment predetermined by Company Pie. The following delimitations have been established in this thesis:

- The shape and dimensions of the new warehouse facility is predetermined, along with location of inbound and outbound docks. Additionally, the dimensions and placement of the refrigerated and frozen areas are static.
- The receiving and shipping operations will be investigated in terms of understanding the current state. However, they will not be a focus in the new DC configuration due to time constraints.
- The automated elements to be considered in the new configuration are limited to AGVs and Automated Pallet Wrapping machine(s), following prior decisions made by Company Pie.
- The Warehouse Management System (WMS), along with other information systems utilised, are regarded as static. This means that the designed warehouse configuration will ensure compatibility with the existing system(s) and will not necessitate implementation of unavailable functions. The thesis will not propose any suggestions for system integration as part of the warehouse consolidation, nor will it include recommendations for system modifications.
- No live implementation, due to the time limit of the project.
- The production area originating from one of Company Rho's facilities will not be included in the study, apart from allocating sufficient space with a suitable placement based on information provided by Company Pie.

Another important factor to address is that the data collection of the thesis centres around collecting quantitative and qualitative data from Company Pie. The Company Rho DC is not in focus due to sensitivity concerns, and information about it will be retrieved from Company Pie. The output recommendation will be relatively general to accommodate the time limitation of 20 weeks in this research project.

1.6 Thesis Structure

Frame of Reference	This chapter introduces all relevant theory for this master thesis. It is divided into the following subchapters, contextual factors, warehouse configuration, perishable goods, and warehouse design.
Methodology	This chapter describes the methodology used in this thesis research. Also, it introduces relevant research strategy and analytical tools to ensure research quality.
Empirical Findings	This chapter presents empirical findings from data and interviews obtained from Company Pie.
Analysis	This chapter identifies and analyses the most influential contextual factors. This chapter bridges empirical findings with theory and suggest configurations to use based on context.
Artefact Development	This chapter presents the final recommendation in the form of an artefact for 2028 and 2034 of the NDC configuration. This is followed by an evaluation and discussion of the artefact's usefulness.
Conclusion	The final chapter of the master thesis includes a conclusion of the research findings and contribution to the knowledge base.

2 FRAME OF REFERENCE

The second chapter in the thesis provides relevant theoretical knowledge to the master's thesis research. This thesis seeks to explore warehouse configuration and contextual factors influencing the choice of configurational elements in a DC. More specifically, it seeks to aid in developing a contextually aligned warehouse configuration for a new facility handling perishable goods in a real-world scenario. The chapter also provides theoretical knowledge of the steps to take when designing a warehouse. Figure 2.1 below illustrates the chapter outline, where four main building blocks, contextual considerations, warehouse configuration, perishable goods, and warehouse design, finally lead to a framework for data collection and analysis.

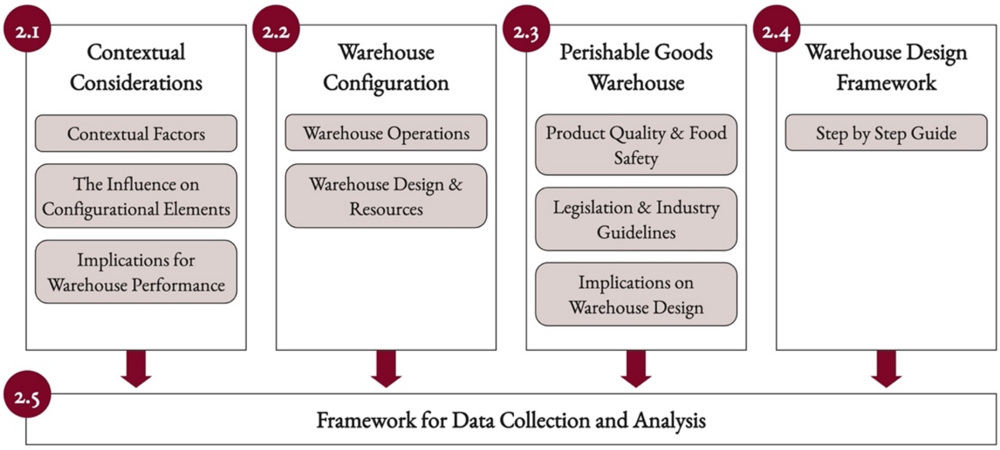


Figure 2.1 The outline of the frame of reference chapter.

2.1 Contextual Considerations

The need to consider various contextual factors, meaning the immediate operating environment, regarding warehouse management is widely accepted (Faber, et al., 2013). Kembro and Norrman (2021) emphasise the importance of understanding how the selection of warehouse configuration is influenced by multiple contextual factors mirroring both the internal and external environment. To stress how both context and configuration influence performance, they present a conceptual contingency framework for warehouse configuration (Op. cit). The framework is illustrated in Figure 2.2 below where the contextual factors and warehouse performance are highlighted to emphasise the focus of the subchapter.

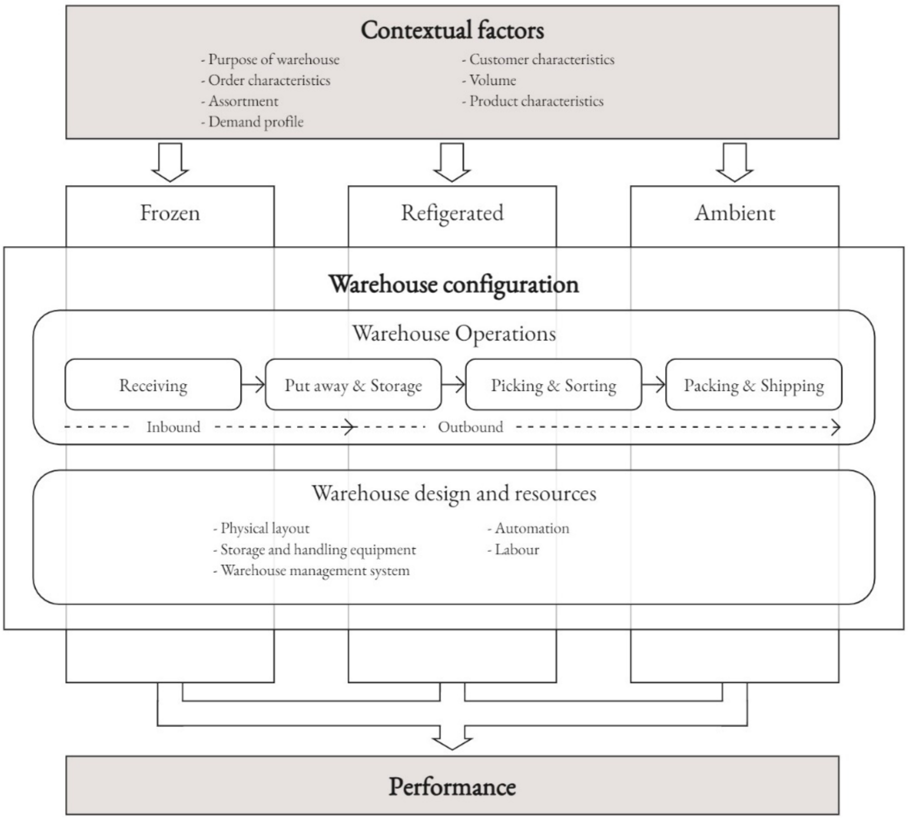


Figure 2.2 Conceptual contingency framework for warehouse configuration, adapted from Kembro et al. (2018) and Kembro & Norrman (2021).

The contingency approach can, at an abstract and simplified level, be described as the effect of one variable on another depending on a third, a so-called contingency factor (Donaldson, 2001). For organisations this translates to a contingency that moderates the effect of an organisational characteristic on organisational performance (Op. cit.). The approach can be widely applied and there is a growing interest towards the contingency approach within warehousing theory (Kembro, et al., 2018; Kembro & Norrman, 2021). The approach involves adapting operations and design to suit specific contexts and proposes that organisations should align their structure and processes with their environments to enhance performance. It asserts that a lack of alignment between warehouse configuration and contingency factors is likely to result in lower performance (Faber, et al., 2017).

Explaining the significant influence that context has on warehouse configuration and performance, it is relevant to recognise what contextual factors are the most influential, what configurational elements are affected, and how these elements are affected.

2.1.1 Contextual Factors

There are varying approaches found in literature on how to categorise and analyse contextual factors related to warehousing. Eriksson et al. (2019) propose three levels; (1) external contextual factors, (2) internal corporate factors, and (3) internal warehouse factors.

The first level consists of factors that are highly dependent on external market development and include customer requirements, product characteristics, volume handled through the warehouse and order characteristics. However, it is possible to attempt changes concerning order volumes and customer requirements with marketing and sales activities. The second level consists of factors that can be influenced by strategic decisions made by corporate management but may not be directly affected by the warehouse manager. Factors include the categorisation of the role of the warehouse in the internal network, the major suppliers, and the delivery strategy. Lastly, the third level relates to the decisions made internally by warehouse management including picking strategy and shipping route optimisation. The study by Eriksson et al. (2019) concludes that there are multiple interdependencies between contextual factors, where one factor can influence another factor, which then can affect a third factor. The three levels and their dependencies are illustrated in Figure 2.3 below.

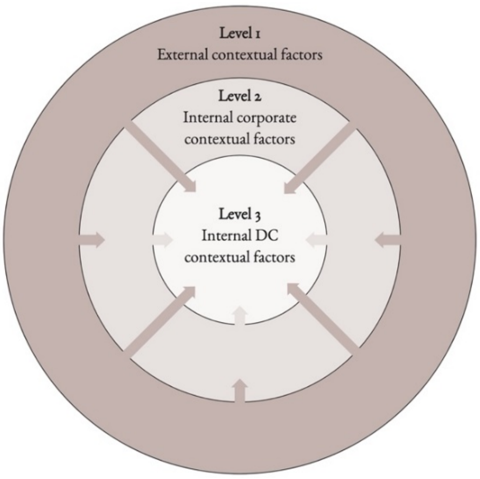


Figure 2.3 The three levels of contextual factors influencing warehouse configuration and their interdependencies based on findings by Eriksson et al. (2019).

The categorisation of contextual factors into three levels also have support in literature on warehouse management. Faber et al (2013) highlight the external warehouse environment, and the internal warehouse system, and Hassan et al. (2015) suggest a more granular structure with the following six categories:

organisational factors, operational factors, structural factors, resources, external environment, and technology. Looking further into existing literature there is a whole variety of contextual factors as well as ways to categorise them. However, common among all authors is that the contextual factors to some extent influence warehouse configuration and performance. In Table 2.1 below, is an overview of contextual factors found in literature. Each factor may have varying significance depending on a certain context, and as such, they should be evaluated individually for each context.

Table 2.1 An overview of contextual factors for warehouses inspired by Kembro and Norrman (2021), Eriksson et al. (2019), and Faber et al. (2013).

Contextual factor	Description	Impact
National legislation	Sets standards and regulations for e.g. safety, labour, and environmental impact.	Impacts cost of labour, requirements on work environment.
Customer characteristics	Customer characteristics refer to the number and type of customers, as well as their preferences.	This impacts the assortment and clarifies whether value adding services are necessary or not.
Demand profile	Includes variance in order profiles and assortment such as seasonality or weekly variations, and thus determine how often SKUs are picked and what volume.	This influence space, storage strategies, labour profiles, and the type of equipment required.
Order characteristics	The number of orders, work-lines per order, and number of each SKU/order.	This impacts the picking process.
Product characteristics	Refers to the attributes of the SKUs, such as their size, weight, fragility, shelf life, temperature requirement, type of packaging and so on.	It has an impact on the space and type of equipment needed.
Assortment	The mix of items offered to the customers, including the different product categories and the types of products within each category.	This impacts the picking process and type of equipment needed.
Corporate strategy	A company's overarching plan to achieve long-term goals and maintain competitive advantage. For example, market expansion, mergers, and acquisitions.	Guides decisions regarding, for example, automation, investments, handled volume, product assortment.
Warehouse role	Refers the role that the warehouse has in the internal network.	Impacts what activities are performed in the warehouse. E.g. kitting, labelling.
Assortment	The mix of items offered, including the different product categories and the types of products within each category. Also, changes over time, e.g. due to seasonality.	This impacts the picking process and type of equipment needed.

2.1.2 The Influence of Context on Configurational Elements

Faber et al. (2013) acknowledge market dynamics and task complexity as main drivers of warehouse planning and control activities, and of the decision rules used. Task complexity measures the depth and breadth of the tasks a warehouse must perform and increases if the number of Stock Keeping Units (SKUs), process diversity, and number of order lines are high. Market dynamics measures the rate of change of the external environment in which a warehouse operates and refers to demand unpredictability and assortment changes.

Contextual factors affect different warehouse operations, where Figure 2.4 shows what Eriksson et. al. (2019) found in their study of which of the different operational processes in an omni-channel warehouse are influenced by which contextual factors.

Level 1 External contextual factors

	Warehouse operations							
Contextual factors	*Receiving*	*Sorting pre-storage*	*Put-away & storage*	*Picking*	*Sorting post-picking*	*Packing*	*Sorting pre-shipping*	*Shipping*
Customer characteristics				x		x		x
Product characteristics			x	x				x
Volume	x	x	x	x	x	x	x	x
Order characteristics				x	x			

Level 2 Corporate contextual factors

	Warehouse Operations							
Contextual factors	*Receiving*	*Sorting pre-storage*	*Put-away & storage*	*Picking*	*Sorting post-picking*	*Packing*	*Sorting pre-shipping*	*Shipping*
DC categorisation	x	x	x					
Suppliers	x	x	x					
Delivery						x	x	x

Level 3 Internal DC contextual factors

	Warehouse Operations							
Contextual factors	*Receiving*	*Sorting pre-storage*	*Put-away & storage*	*Picking*	*Sorting post-picking*	*Packing*	*Sorting pre-shipping*	*Shipping*
Picking strategy	x	x	x		x	x		
Shipping route optimisation				x			x	

Figure 2.4 Contextual factors influencing the configuration of warehouse operations based on (Eriksson, et al., 2019).

2.1.3 Implications for Warehouse Performance

After looking into what configurational elements are affected, it is interesting to see how they are affected, and how that in turn reflects on overall warehouse performance.

A study by Kembro and Norrman (2021) shows how contextual factors create different challenges, thereby influencing the choice of the configurations. In addition to market dynamics and task complexity, the study describes four categories of the factors and related challenges that are particularly important in omnichannel: speed, space, economies of scale and tied-up capital. The findings highlight the importance of understanding context and imply that multiple challenges may require trade-offs when selecting configurations, for example, regarding what storage, processes, and resources to integrate or separate.

Kembro and Norrman (2021) present a spider web framework, which is visualised in Figure 2.5 below, that could guide retailer in reaching different configuration goals based on their contextual profile. Depending on the identified contextual factors there are different configurational challenges. If a certain context is highly affecting the warehouse, it drives future configurational goals.

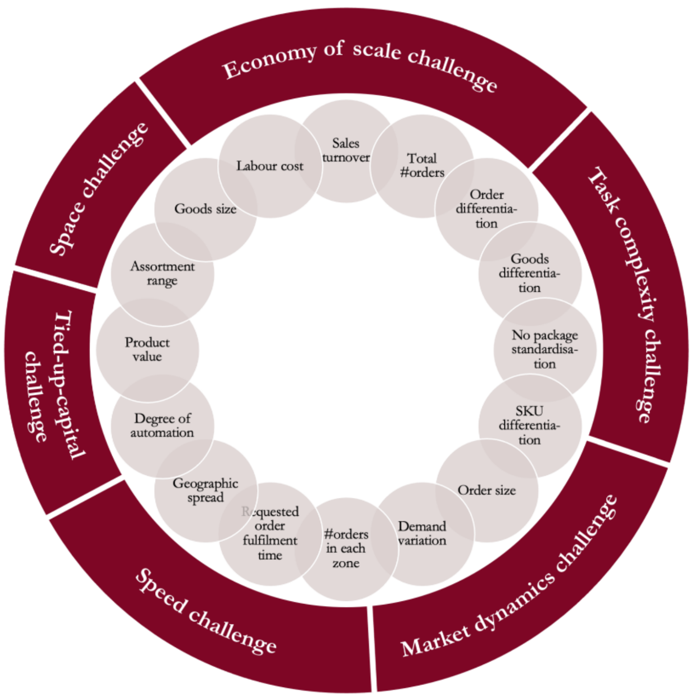


Figure 2.5 Framework for contextual profiling and links to corresponding challenges adapted from the framework proposed by Kembro & Norrman (2021)

2.2 Warehouse Configuration

Warehouses are pivotal not only from a customer service perspective, but also from a cost perspective. Figures from the European Logistics Association show that, for Europe, warehouse capital and operating costs make up around 25 percent of logistics costs (Baker & Canessa, 2009). Space and time are significant cost drivers in warehouse management (Richards, 2018), and according to Rouwenhorst et al. (2000) warehousing costs are largely determined at the design phase. A warehouse configuration consists of multiple configurational elements. The Figure 2.6 below, visualises the configurational elements in a warehouse and highlights its position in the contingency framework. According to Richards (2018) the goal of most warehouses is to increase throughput rates and reduce the amount of stock held.

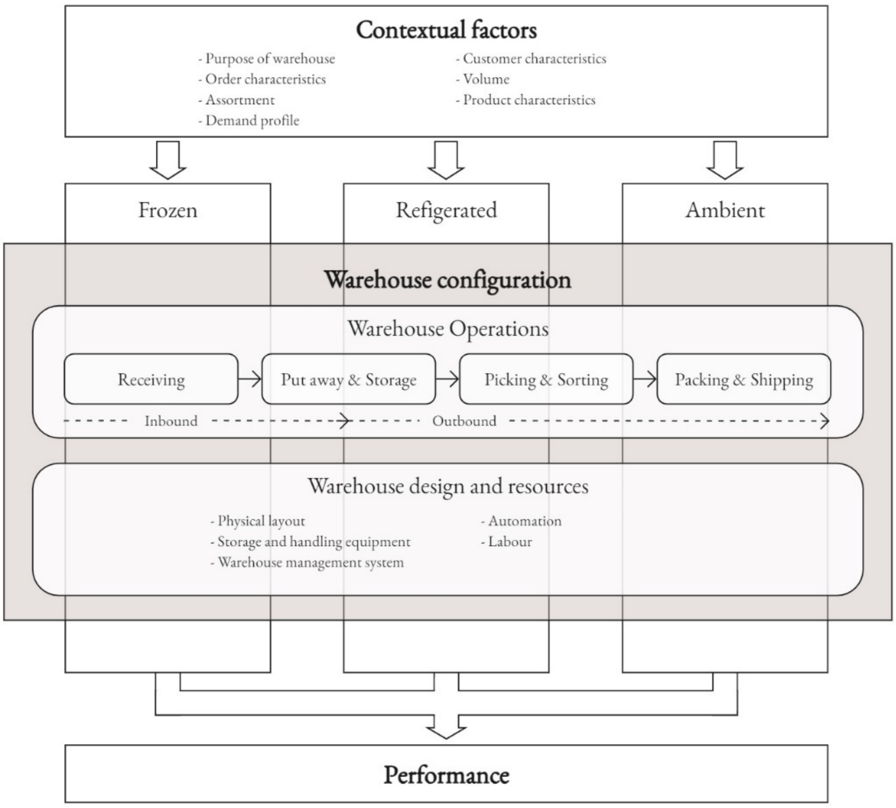


Figure 2.6 An overview of warehouse configuration, adapted from Kembro et al. (2018) and Kembro & Norrman (2021)

The configurational elements can be divided into operations, and design and resources. The following subchapters will therefore explore existing literature on operations, including receiving, put away and storage, picking and sorting, and packing and shipping. Thereafter, it will describe design and resources in terms of physical layout, storage and handling equipment, warehouse management system, and automation.

2.2.1 Warehouse Operations

Operations within a warehouse can be classified into inbound and outbound (Bartholdi III & Hackman, 2019). The inbound operations consist of receiving and put-away, the outbound operations consist of picking, packing, and shipping (Bartholdi III & Hackman, 2019; Frazelle, 2002; Rouwenhorst, et al., 2000). According to Bartholdi III and Hackman (2019) a general rule of thumb in warehouse operations is that product should flow continuously through these operations to avoid double-handling and product should be scanned at all key decision points. This enables response to customer demand through total visibility of assets (Op. cit).

Receiving

Receiving refers to the activities involved in orderly receipt of materials coming into the warehouse, assuring that the materials are of the quality and quantity ordered, placing materials to storage or other organisational functions (Rouwenhorst, et al., 2000; Frazelle, 2002). Usually, receiving begins with a notification of the arrival of goods (Bartholdi III & Hackman, 2019). When the product has arrived, it is staged for storage by scanning and inspection for quality. If damaged or inaccurate deliveries are stored inside the warehouse, damaged or inaccurate shipments are likely to be distributed from the warehouse (Frazelle, 2002).

Put Away and Storage

In a warehouse, placing product into storage is termed put-away. It usually includes material handling, location verification, transportation, and placement of product in the accurate location (Frazelle, 2002). In some operations, goods are also sorted pre-storage, by for example splitting up mixed pallets (Eriksson, et al., 2019). The put away operation starts by determining an appropriate storage location for the SKUs. This entails that information on storage location availability, and for example size and weight restrictions must be available (Bartholdi III & Hackman, 2019).

When a storage location has been determined and the product is placed in the location, the storage location should be recorded. This is usually done by scanning a barcode at the location (Bartholdi III & Hackman, 2019). This helps in creating an efficient picklist to guide the picking operations later (Op. cit). The orientation in which the pallets are placed in the storage location also affects later operations. A study by Glock et. al. (2019) indicate that by reducing the need for excessive bending and stretching when retrieving items harder to access farthest to the back of pallets, both the order picking time and the spinal load on the workers can be reduced. One way to accomplish this is to place pallets with the long side facing the aisle instead of the short side. Pictures clarifying short and long side handling are found in Appendix IV and V. Additional research shows that pallet loading and unloading tasks in which a worker picks up items close to the floor, and stretch across large horizontal distances, poses a significant risk of lower back disorders (Pankok Jr. & Hoyleb, 2015).

When goods are put-away into storage, the company's storage policy is taken into consideration. Storage policies which are frequently discussed in literature include dedicated storage, random storage, class-based storage, correlated storage, and family grouping (Kembro, et al., 2018; Thomas & Meller, 2014; Bartholdi III & Hackman, 2019). A dedicated storage strategy entails that a particular location is prescribed for each product that is stored. A random storage strategy leaves the storage decision to the operator. Class-based storage, or ABC zoning, which is a storage allocation method that allocates zones to specific product groups. Storing correlated items in the same or nearby locations can reduce the travel time and therefore picking cost (Frazelle, 2002). Correlations can be such as items in repair kits, items from the same supplier, items in the same assembly, items of the same size (Frazelle, 2002; Richards, 2018). A simple way to identify demand families is to rank pairs of items based on the number of times the pair appears together on an order (Op. cit). To assess a storage policy, a heat map can be used (Hagle, 2024). See Figure 2.7 below for a visualisation of a heatmap.

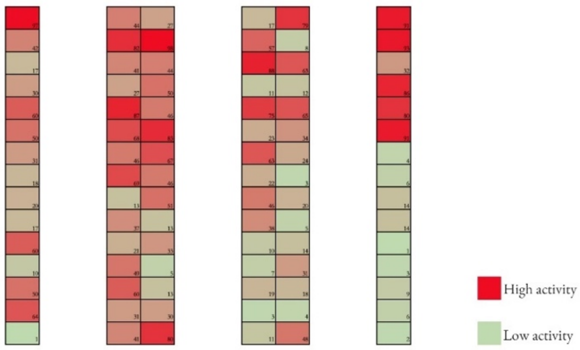


Figure 2.7 An visualisation of a general heat map where the red colour symbolises locations with high activity and the green colour locations with low activity, inspired by (Hagle, 2024).

The storage method can depend on factors such as size, quantity and handling characteristics of the product or its container (Frazelle, 2002). An important decision in the design stage of a warehouse is the process flow (Rouwenhorst, et al., 2000; Frazelle, 2002). Examples of this include storage space optimisation and storage mode optimisation. Storage mode optimisation refers to by which means that each item should be housed in storage. The storage mode should minimise the holding cost and storage cost of that item (Frazelle, 2002). Decisions include for example whether pallets be assigned position in floor storage, single-deep racks, double-deep racks, or mobile racks. Another decision that can be decided is how high and deep the storage mode should be, Bartholdi III & Hackman (2019) present Equation 1 to calculate optimal lane depth.

Equation 1 To calculate the optimal lane depth for SKU i with q_i pallets stackable z_i high, where a refers to the aisle width in the unit SKUs. (Bartholdi III & Hackman, 2019).

$$Optimal\ lane\ depth\ = \sqrt{\left(\frac{a}{2}\right)\left(\frac{q_i}{z_i}\right)}$$

Storage space optimisation revolves around deciding whether to establish a forward picking area separate from the reserve picking area (Frazelle, 2002). In the reserve area, products are stored in the most economical way and in the forward area products are stored for easy retrieval by an order picker (Rouwenhorst, et al., 2000). Transfer of items from the reserve area into the forward area is called replenishment. If a forward picking area is established, the size of this area needs to be determined (Frazelle, 2002). If the storage system has a reserve area, a storage policy for that area is also needed (Rouwenhorst, et al., 2000).

To conclude, put away and storage in warehouse operations entail placing goods in a beneficial location to improve the material flow. A summary of the different storage strategies and policies can be seen in Table 2.2 below, including when each of the practices is most beneficial.

Table 2.2 Summary of practices for product storage allocation based on Bartholdi III and Hackman (2019), Thomas and Meller (2014), Kembro et al. (2018), and Frazelle (2002).

Storage Strategy		
Practice	**Description**	**When**
Dedicated	Each product that is stored gets a prescribed storage location.	For products with special requirements, e.g. heavy weights. Popular items can be placed in more convenient locations. It allows for workers to learn SKU placement. It might decrease space utilisation.
Random	Products do not have assigned locations in the warehouse and can be placed randomly.	To get efficient space utilisation in bulk storage. Random storage decreases the risk of congestion since popular items are not placed together.
Storage Allocation Method		
Practice	**Description**	**When**
Class based storage	Also known as ABC zoning. Products are assigned to a location based on pick frequency	Suitable for large differences in SKU popularity. Storing similar items in the same or nearby locations can reduce travel time and picking cost.
Family grouping	SKUs with similar characteristics are stored together.	Developing a storage allocation method based on SKU attributes rather than demand pattern can reduce retrieval time.
Correlated storage	Similar SKUs that are requested together are stored together	When products are frequently requested together it can save time to place them near each other.

Order Picking

When there is a demand for a product in storage, the process of order picking is initiated. Frazelle (2002) states that picking is the function around which most warehouse design is based. As order picking is typically the most expensive activity in a warehouse, there is extensive literature on the subject of how to conduct this activity as efficiently as possible (Frazelle, 2002; Roodbergen & Vis, 2006; Bartholdi III & Hackman, 2019; Richards, 2018). Much of the design of the order-picking process is centred around reducing the time spent on traveling (Bartholdi III & Hackman, 2019).

There are typically three steps to an order-picking operation (Bartholdi III & Hackman, 2019). First, when a customer order is registered, the Warehouse Management System (WMS) must check if there is inventory available to ship. Second, a pick list to guide the order-picking must be provided, and finally, necessary shipping documentation and schedule for the shipping and order-picking must be provided (Frazelle, 2002; Bartholdi III & Hackman, 2019).

The overall picking strategy used in a warehouse is an important configurational decision. Either orders can be picked by one picker at a time, in serial picking, or by multiple pickers which is called parallel picking (Bartholdi III & Hackman, 2019). While serial picking can be more time consuming, parallel picking requires more coordination and consolidation of the pickers work (Op. cit.).

The pick list to guide the order-picking can be interpreted as a shopping list for the pickers. Each entry on the list is called an order-line and consists of the SKU and the quantity requested (Bartholdi III & Hackman, 2019). The WMS checks the inventory for availability of each order-line and can also reorganize pick list order to better match with the layout and operations of the warehouse. The number of pick-lines is an indication of the labour required to complete an order-line, since each pick represents a location in the warehouse that must be visited (Bartholdi III & Hackman, 2019). The manual work elements involved in order picking are summarised in Table 2.3 below. When work elements cannot be eliminated, they can, in some cases be combined to improve picking productivity (Frazelle, 2002).

Table 2.3 The manual work element involved in order picking according to Bartholdi III and Hackman (2019).

Work Element	Description
Traveling	To, from, and between locations
Extracting	SKUs from storage locations
Reaching and bending	To access storage locations
Documenting	Picking actions
Sorting	Items into orders
Packing	Items before shipping
Searching	For pick locations

An important decision to consider is which picking policy to implement. Literature has explored various picking policies, including single-order picking, where one order is picked per tour, and batch picking, where a group of orders is picked together during a single tour (Gu, et al., 2007). Batching involves grouping different customer orders into batches to be picked simultaneously during one tour. After picking, the accumulated items are consolidated and sorted within a specific time frame before proceeding to the next batch (Gu, et al., 2007). This method is advantageous for small orders, contrasting with single order picking where each tour is dedicated to one specific order (de Koster, et al., 2007). However, it is important to note that batching requires additional tasks such as sorting, adding complexity to the process.

To guide in what way the picking operation is conducted in a warehouse several pick methods exist. Pick by individual order, cluster picking, zone picking, wave picking and goods to picker are methods mentioned in literature (Richards, 2018; Petersen & Aase, 2004). When picking by individual order an operator takes one order, or one part of the order, and travels to all pick locations to complete the assignment (Richards, 2018; Petersen & Aase, 2004). This method allows for flexibility and ability to isolate urgent orders but has a low pick rate and is labour intensive (Richards, 2018).

A way to improve picking time and reduce travel is to apply a cluster picking method in which operators pick multiple orders during the same travel route. This is mostly done in warehouses that have smaller items and requires equipment that can hold multiple orders (Richards, 2018). Another way to improve pick efficiency is to apply a zone picking method in which products are picked from specific areas in the warehouse and operators are assigned separate picking zones (Richards, 2018; Petersen & Aase, 2004). Finally, a warehouse can also use a goods to picker policy to eliminate picker travel time and reduce labour (Richards, 2018). A summary of the pick methods is found in Table 2.4 below.

Table 2.4 Different picking methods and in which cases to apply them based on Richards (2018) and Petersen & Aase (2004)

Picking Method		
Method	**Description**	**When**
Pick by individual order	Pick one order at a time.	Most operations, flexible and gives ability to isolate urgent orders. However, low pick rate, labour intensive, and can create bottlenecks.
Cluster picking	Multiple orders picked at the same time.	Most operations, but typically smaller items. Particularly useful when there are common items across multiple orders. Reduced travel, and reduced pick time.
Zone pick	The warehouse is divided into zones where pickers are assigned to a specific zone(s).	When there are many SKUs and low to moderate number of items per order line. Can lead to less travel and can accommodate different product families in orders. Might require conveyors and can create idle time if work is unbalanced.
Wave pick	Orders are grouped into waves to match shipping and schedule times.	When orders are released on a timed basis or to meet departing trucks. Allows for effective work scheduling and is highly efficient if you're picking many orders that contain the same items. However, urgent orders cannot be separated easily.
Goods to picker	Items are brought to the picker contrary to picker travelling to the item.	High intensity picking operations. Increases pick rates, accuracy, space requirement, security, and ergonomics. However, equipment and energy cost are high and there is a requirement of having standardized unit loads.

Furthermore, routing can improve efficiency. Several routing policies have been suggested in literature for order picking (Bartholdi III & Hackman, 2019; Hwang, et al., 2004; Thomas & Meller, 2014; Petersen, 1997). An illustration of the different routing policies can be viewed in Figure 2.8. In the transversal policy the order picker enters every aisle that contains at least one order-line, traverses the entire aisle, and exits at the opposite end of the aisle (Thomas & Meller, 2014). Another policy is the return policy which entails that the picker enters an aisle, travels to the farthest pick and then returns to the same end of the aisle as they entered (Bartholdi III & Hackman, 2019). The next policy is the midpoint strategy where an order picker only travels to the midpoint of an aisle before returning (Thomas & Meller, 2014). Picks past the midpoint are retrieved from the back cross aisle. A strategy similar to the midpoint strategy is the largest gap strategy (Hwang, et al., 2004).

In the largest gap strategy, the largest gap refers to the part of the aisle that is not visited by the picker. If the largest gap is between two adjacent picks, a return route from both ends of the aisle is performed. If not, a return route from one end of the aisle is performed. (Hwang, et al., 2004). Lastly, the composite strategy combines the traversal and return policies by stating that an aisle is not traversed if returning results in less travel (Thomas & Meller, 2014). Studies show that regardless of storage policy an elongated warehouse is favourable if the retrieval and ship point is centrally located, and that the largest gap strategy is preferred for a smaller number of pick lines (Op. cit). However, in general the midpoint policy outperforms both traversal, which is the most used strategy in practice, and return policy in terms of minimizing order picking travel (Hwang, et al., 2004). Moreover, a highly skewed ABC curve can significantly reduce travel regardless of routing policy (Op. cit).

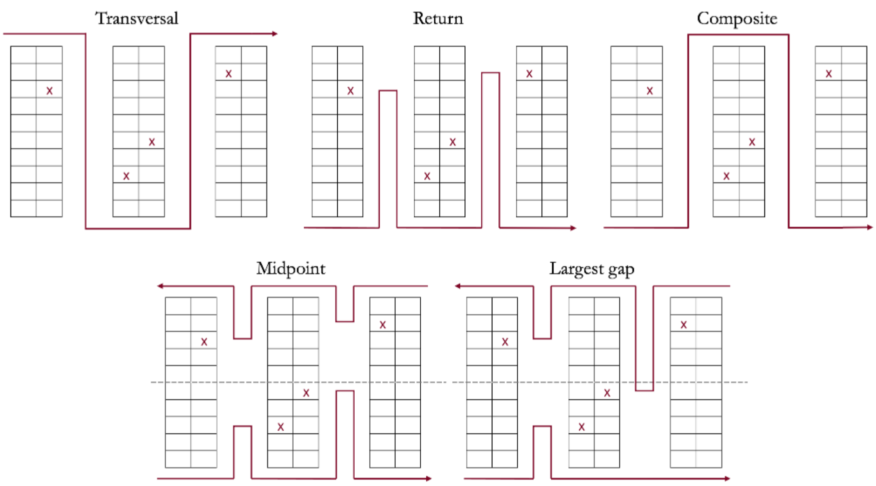


Figure 2.8 A visualization of routings adapted from (Hwang, et al., 2004).

Packing and Shipping

Before orders can be shipped, they usually need to be packaged. During packaging there is usually an opportunity to check that the customer order is complete and accurate. Inaccurate orders generate returns which can be up to ten times as expensive as shipping the product out (Bartholdi III & Hackman, 2019).

Shipping usually handles larger units than picking since the packaging has consolidated the items into fewer containers. Therefore, there is less labour involved in this process, although some walking may be required if product is being staged before loading into shipping containers. Staging freight causes double handling, and therefore more work, but is required in some cases.

Operational Configuration Options

To conclude the literature review of warehouse operations, the different configuration options are presented in Table 2.5 below.

Table 2.5 Summary of the different practices in storage and picking operations.

Storage	
Policy	**Reason**
Dedicated	Can account for special requirements of SKUs but decreases the space utilisation.
Random	Enables higher utilisation but has longer travelling distances.
Class based	When there is a large difference in SKU popularity.
Correlated	When it is advantageous to store SKUs together because of for example temperature requirements.
Family grouping	SKUs that are frequently requested together are stored together.
Picking Strategy	
Strategy	**Reason**
Serial	One worker per order, does not require sorting.
Parallel	Multiple workers per orders, requires sorting.
Picking Method	
Method	**Reason**
Pick by individual order	To allow for flexibility and be able to isolate urgent orders
Cluster piking	To be able to pick multiple orders at the same time
Zone pick	To be able to reduce travel distance and increase pick efficiency
Wave pick	To be able to have effective scheduling and if there are multiple orders that contain the same items.
Goods to picker	To streamline highly intensive standardised picking operations.

2.2.2 Warehouse Design and Resources

For the success of any business, it is imperative that its warehouses are designed to be as efficient as possible. Warehouse design and resources refers to the physical layout, storage and handling equipment, WMS, and automation (Kembro, et al., 2018). The layout can play either positively or negatively in terms of meeting the organisation's goals (Kamali, 2019). The design of a warehouse can become outdated due to various factors such as changing company strategy, advances in technology, and business expansion (Yener & Yazgan, 2019). Factors that should be analysed when reconfiguring the layout in such cases are investment and operational costs, volume and mix flexibility, throughput, storage capacity, response time, and order fulfilment quality (Op. cit).

Physical Layout

According to Rouwenhorst et al. (2000) the warehouse storage capacity is largely determined by the dimensions and type of storage system rather than the storage policy. The most optimal design is one that meets today's operational requirements as well as accommodates to future growth by being flexible, scalable, and relatively inexpensive to adapt (Richards, 2018). Configurational elements to consider when designing a layout is the location of receiving and shipping, aisle configuration and space utilisation (Bartholdi III & Hackman, 2019; Thomas & Meller, 2014). The idea is to design for the future, whilst building for today (Richards, 2018).

If the location of receiving and shipping is in the middle of opposing sides of the warehouse, the warehouse has a flow-through configuration. In a flow through configuration, there are many locations of equal convenience (Bartholdi III & Hackman, 2019). This type of configuration is appropriate for extremely high volumes and when the building is long and narrow (Op. cit). This layout is visualised on the left-hand side in Figure 2.9 below. When receiving and shipping share the same dock, there are very few convenient locations as well as some very inconvenient locations. This is called a u-flow configuration and can be appropriate when the product movement has a strong ABC shew (Bartholdi III & Hackman, 2019). It might also be beneficial to use a cross-dock area in these cases. If a cross-dock area is implemented it may be reasonable to use drive-in racking or push-back racking in the despatch area to minimise product damage and increase utilisation (Richards, 2018).

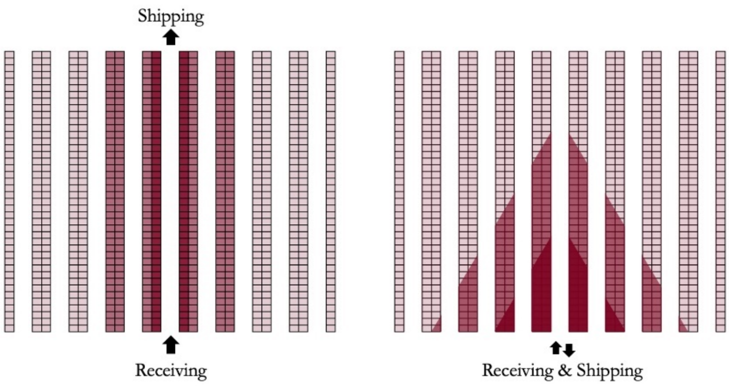


Figure 2.9 Flow through layout to the left and u-flow layout to the right. Adapted from Bartholdi III & Hackman (2019).

Warehouses usually have single- or double-deep pallet racks arranged in parallel picking aisles, allowing workers to travel between aisles to pick items for to place in their picking carts, or forklifts with empty pallets. To reduce travel, large order picking warehouses usually have at least one cross aisle (Gue & Meller, 2009). Cross aisles allow for shorter travel between storage locations (Bartholdi III & Hackman, 2019). However, they require additional space and can result in longer picking tours in cases where the pick density is high (Thomas & Meller, 2014). Another type of layout for storage space is the fishbone layout. According to Gue and Meller (2009) a fishbone layout can offer a 20 percent cut in expected travel distance in a unit-load warehouse. The best fit for a fishbone-layout is in a single command unit-load warehouse (Cardona, et al., 2012). They allow for more direct travel between storage and a central location for u-flow receiving and shipping (Bartholdi III & Hackman, 2019). These layouts are visualised in Figure 2.10 below.

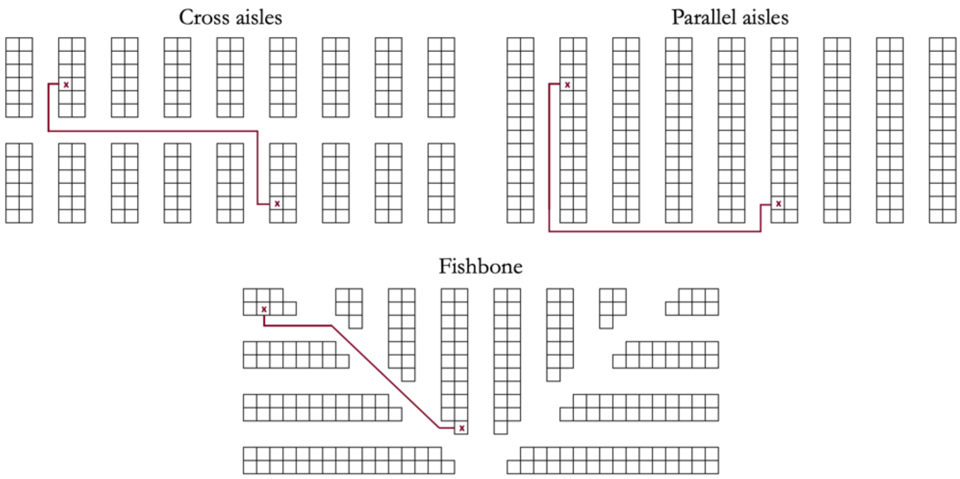


Figure 2.10 Different layout types adapted from Bartholdi III & Hackman (2019).

To achieve a higher degree of space utilisation in a warehouse, there are two layout decisions that can be made, taking advantage of vertical space and/or using deep lanes (Bartholdi III & Hackman, 2019). When stacking pallets that are heavy or fragile, or have uneven top surfaces, racks can be used to allow for vertical storage. The benefit of vertical storage is reduced labour by easing storage and retrieval, which might create additional pallet positions, as well as to protect the product from damage, and it might provide a safer work environment (Op. cit). A tool that can help visualise the movement between aisles in a warehouse and therefore provide valuable insight about the warehouse is a spaghetti diagram (Quinn, 2023). An illustration of an arbitrary spaghetti diagram can be viewed in Figure 2.11 below.

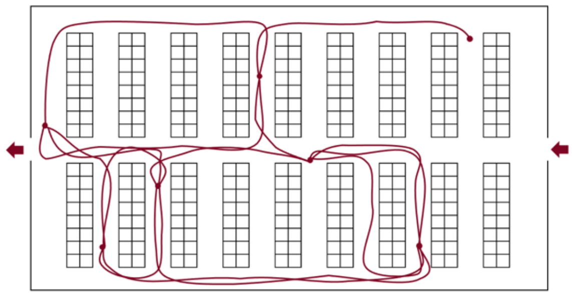


Figure 2.11 Spaghetti diagram where the movement is marked with red lines, inspired by Quinn (2023).

The final central aspect in a warehouse layout is aisle width (Richards, 2018). Aisles space should be reduced to the minimum necessary space that provides adequate accessibility (Bartholdi III & Hackman, 2019). The aisle width is determined by the size of pallet carried and the turning circle of a forklift truck (Richards, 2018). However, there are exceptions to this rule, narrow aisle and hand pallet trucks operate in aisles based on width of the truck itself (Richards, 2018). The minimum aisle width can be provided by the manufacturers of the forklift trucks (Op. cit).

Storage and Handling Equipment

The equipment used in a warehouse can be classified as storage equipment, for example the racks used to store pallets, and handling equipment, for example trucks used to move product around the warehouse (Bartholdi III & Hackman, 2019). Equipment used to store and handle product in a warehouse can reduce labour costs (Bartholdi III & Hackman, 2019). Storage equipment can reduce costs by allowing more SKUs to be on the pick face, thereby increasing the pick density and reducing travel per pick. It can also increase space utilization by for example enabling the option of storing the product vertically. Another benefit is that handling equipment reduces the labour cost by moving product faster around the warehouse (Bartholdi III & Hackman, 2019). As the automated elements considered in the thesis are predetermined by Company Pie and do not include alternatives for sorting automation, these alternatives are not covered below.

There are two taxonomies when it comes to storage equipment, pallet storage systems and pallet handling systems (Frazelle, 2016). Pallet storage systems fall into three subcategories based on racking type, pallet stacking system, static racking systems, and dynamic racking systems. In pallet stacking systems pallets are stacked on top of each other, usually in lanes (Bartholdi III & Hackman, 2019). The advantage of pallet stacking systems is that they usually require low investment cost, and several loads of the same SKU are received and/or withdrawn at one time. However, they are not always optimal for storing FIFO goods, and special considerations need to be made in such cases (Frazelle, 2016). When storing pallets in a lane, as soon as a SKU is placed in the lane, the entire lane is reserved for that SKU to avoid double-handling. This leads to a loss of space which is called honeycombing (Bartholdi III & Hackman, 2019).

Static racking systems refer to racking systems in which pallets have static locations (Frazelle, 2016). On the contrary, pallets in dynamic racking systems can move within the rack (Op. cit). Pallet storage and retrieval systems should be selected conjunction with one another, and the key is to determine the proper storage and retrieval combination for each item (Frazelle, 2016; Bartholdi III & Hackman, 2019). In Table 2.6 below pallet storage systems and pallet handling systems are introduced together withs their use.

Table 2.6 Different types of storage and handling equipment and its uses based on Frazelle (2016) and Bartholdi III & Hackman (2019).

Storage equipment		**Use**
Static racking systems	Single-deep pallet racks	Stores pallets one deep. More freedom to retrieve individual pallets but requires more aisle space.
	Double-deep pallet rack	Pallets are stored two deep. Slightly more work is required to store and retrieve product but requires fewer aisles. Special truck needed to reach beyond first pallet position
	Drive-In/Drive-through	A lift truck can drive within the rack frame to access interior locations. Allows for FIFO-policy but should be thought of as a floor-storage for product that is not stackable.
	Cantilever racks	Used to store long objects.
Dynamic racking systems	Push-back rack	Provide LIFO deep -lane storage.
	Pallet flow rack	Loads are conveyed in the rack on skate-wheeled conveyors from the back of a storage lane to the front. Allows for FIFO and has high throughput and good space utilisation
	Mobile pallet racks	Single-deep pallet racks that can be moved to create aisles.
Handling equipment		**Use**
Counterbalance lift trucks		Versatile truck that can be used for handing pallets.
Reach and double-reach lift truck		Fork can be extended to access positions in double deep rack.
Narrow aisle vehicles		If aisles are narrow, different handling equipment is used to retrieve SKUs.
Hand pallet trucks		Lifts pallets sufficiently to be able to move them across the warehouse floor.

Warehouse Management System

A WMS is a software package that helps manage inventory, storage locations, workforce, and operations (Bartholdi III & Hackman, 2019). Typically, the WMS keeps information about every SKU in the warehouse and about the warehouse configuration. A WMS can have varying degrees of sophistication, but some core capabilities of a WMS is the ability to record receipts from receiving and shipping, locating stock and equipment, and directing warehouse activities.

Automation

The introduction of robotics, automation, and software systems into warehouses has the potential to revolutionize logistics operations, akin to the impact of the invention of the wheel (Richards, 2018). However, not all warehousing operations may immediately benefit from such advancements or afford the initial investment in technology. Automating inefficient processes might expedite them but will not necessarily improve overall efficiency (Richards, 2018). Labour-intensive processes are typically automated first, with a growing emphasis on automating inbound operations as warehouses evolve to handle diverse orders, flows, and goods (Kembro & Norrman, 2022). As warehouses expand, the introduction of multiple zones may prove beneficial, with different technologies employed depending on the zone's requirements (Op. cit.).

Automated Guided Vehicles (AGV) include a broad range of technology, with literature covering a wide variety of systems, functions, capabilities, and situations. AGVs were mainly developed to eliminate travelling time of human workers (Yildirim, et al., 2023). Today, the technology has evolved into a reliable tool and an important part of modern intralogistics within warehouses. However, it is important to understand that it comes with several limitations. Mixing AGVs with human workers hinders the efficiency of AGVs since the machines are forced to slow down, or stop, when they are nearby a human worker (Zuin, et al., 2020).

Design and Resources Configurational Elements

To provide an overview, different configurational elements related to design and resources are summarised in Table 2.7 below.

Table 2.7 A summary of physical layout and equipment decisions.

Physical Layout		
Decision	**Variations**	**When**
Location of receiving & shipping	U-flow	When there is a high skew in product popularity. Provides few locations with great accessibility.
	Flow-through	For high volume warehouses. Allows for many locations with good accessibility.
Aisles	Parallel aisle	Best suited for small to medium businesses and low to medium throughput.
	Cross aisle	Supports movements between storage locations.
	Fishbone	For less travel between aisles but has lower space utilisation.
Space utilisation	Horizontal	To decrease costs.
	Vertical	To increase volume utilisation.
Storage and handling equipment		
Decision		**When**
Static racking systems		Pallets have static locations
Dynamic racking systems		Pallets move
Handling equipment	Manual	In most warehouses, allows for flexibility.
	Automatic	In high volume warehouses with a standardised handling unit.

2.3 Perishable Goods Warehouse

Given the real-world scenario central to this thesis, it is crucial to consider the added layer of complexity in the warehouse configuration when dealing with perishable goods. Figure 2.12 below highlights how the presence of goods requiring different temperature zones permeates all aspects of warehouse configuration, including the design phase.

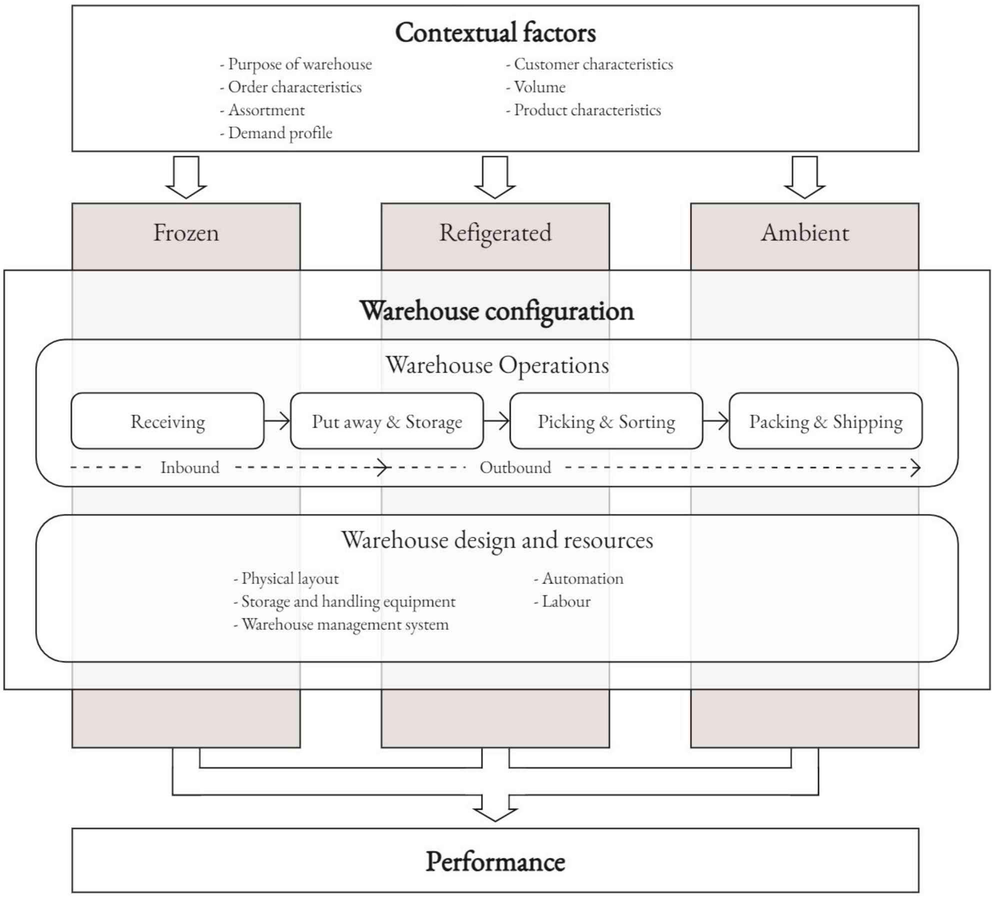


Figure 2.12 Conceptual contingency framework for warehouse configuration including the temperature zones required in a perishable goods warehouse, adapted from Kembro et al. (2018), Kembro & Norrman (2021) and Eriksson et al. (2019).

Most perishable goods have strict environmental requirements, which need to be considered throughout the entire supply chain, adding an additional layer of complexity to perishable goods warehouses in comparison to traditional warehouses (Aung & Chang, 2023). Additionally, Yurtseven et al. (2022) state that the design and operation requirements may differ for a cold warehouse and highlight observations that indicate there are rather different design parameters to consider for cold storage. This includes designing based on storage requirements of the products, mainly temperature, and minimising heat loss to save energy which contributes to lower operating costs and reduce the environmental footprint.

2.3.1 Product Quality and Food Safety

The market for perishable goods is increasing, and much of the food safety around these goods revolves around keeping the goods at the right temperature (Stragas & Zeimpekis, 2011). Time spent in the warehouses, as well as the dry storage conditions, determine the quality and remaining shelf-life of the perishables (Piramuthu, 2022). Preservation of quality and safety is incremental, posing several challenges associated with perishable goods in warehousing (Stragas & Zeimpekis, 2011). Examples include temperature monitoring, product tracking, products storage location, expiry date control and incoming quantities forecasting (Op. cit.).

When designing a perishables warehouse, the specific storage requirements of the goods to be stored need to be accounted for (Yurtseven, et al., 2022). This is in line with the contingency approach previously introduced and emphasises the importance of the product characteristics as an external contextual factor.

There are several risks related to food quality when frozen and cold foods are handled in a warehouse. Nilsson et al. (2009) state that the single most significant factor affecting quality is the product temperature since it largely determines the product's shelf life and the time until a certain quality change occurs. To preserve product quality the FIFO principle should be followed, and temperature should be maintained during storage (Op. cit.). Table 2.8 below presents some common risks related to quality as well as suitable preventative measures.

Increasing consumer interest and awareness of quality and safety have led to increased demands for correct product temperature upon delivery to retailers and households (Nilsson, et al., 2009). This requires lower temperatures in distribution to stores and/or shorter shelf lives for many food items (Op. cit). Over time warehousing activities have become increasingly complex and comprehensive with increased requirements for delivery optimisation, flexibility, and cost-effectiveness because of consumer demands, and the perishable food industry is no exception (Frazelle, 2016; Vanickova, 2019). The increasingly stringent requirements are reflected in increasingly strict food legislation with specific requirements for responsibility and management (Richards, 2018). Special emphasis is placed on supervision to ensure quality and food safety.

Table 2.8 Quality risk assessment of frozen and cold foods for warehousing activities based on information from the Swedish trade association Djupfrysningsbyrån (Nilsson, et al., 2009).

Frozen foods		
Activity	**Quality risk**	**Preventative measures**
General handling	The growth of naturally occurring or introduced microorganisms with properties to spoil food and/or cause illness.	Low controlled temperature.
		Prompt handling outside controlled temperature range.
Storage	The products undergo dehydration, resulting in the formation of "snow" and ice within the packaging due to temperature fluctuations.	Consistent temperature through quality freezing equipment, and monitoring of refrigeration machinery.
		Prevent cold air loss upon opening.
		Avoid freezing in storage freezers.
	Surface dehydration occurring due to direct air circulation on the product.	Airtight packaging for products intended for long-term freezing
	Fat within the product oxidizes due to prolonged exposure.	Limited shelf life for fatty products.
		Effective production planning to ensure rapid turnover of inventory.
		Adherence to the FIFO principle.
Loading, unloading, put-away & picking	Partial thawing of the product leads to deformation and deterioration of its consistency.	Picking occurs in temperature-controlled environments or for a short duration.
Cold foods		
Activity	**Quality risk**	**Preventative measures**
General handling	The growth of naturally occurring or introduced microorganisms with properties to spoil food and/or cause illness due to prolonged exposure to high temperature.	Good and clean raw materials.
		Rapid cooling and controlled temperature.
		Prompt handling outside temperature-controlled areas.
Storage	Deterioration in consistency and loss of moisture if the product freezes due to excessively low temperature.	Higher temperature than the product's freezing point.
Loading, unloading, put-away & picking	Growth of product-spoiling or illness-causing microorganisms due to excessively high temperature.	Low temperature with good margin to maintain a buffer.
		Handling in temperature-controlled environments and for a limited time.
		Avoid co-loading goods with different temperature requirements.

2.3.2 Legislation and Industry Guidelines

When handling outside temperature-controlled spaces, the handling time must be limited to restrict or avoid a temperature increase in the product (Nilsson, et al., 2009; Richards, 2018). This means that sensitive products or products with a high temperature should be given priority in handling. In the absence of temperature measurement in the product, the goal should be not to exceed 30 minutes for frozen goods on a pallet or 10 to 20 minutes for refrigerated goods on a pallet (Nilsson, et al., 2009). The temperature losses can vary between 0 and 5°C or more which emphasises the importance of having a temperature reserve (Op. cit.). However, since refrigerated products should not be stored below their freezing point the requirements for these are narrower requirements.

2.3.3 Implications on Warehouse Design

Mismanagement during storage can lead to significant economic losses in the form of waste. It can be waste caused by improper storage and handling, leading to damage requiring product disposal (Richards, 2018). Another type of waste is the complaints made for various reasons, such as temperature deviations (Nilsson, et al., 2009). During storage, products should be positioned so that there is an air gap between the products and the walls of the space to ensure good air circulation and avoid thermal bridges (Op. cit.).

As many handling processes as possible should take place in temperature-controlled spaces to avoid temperature increases and thus quality and energy losses (Nilsson, et al., 2009). Every handling, transport, or storage of the refrigerated or deep-frozen product outside a temperature-controlled environment constitutes a critical moment in handling from a temperature perspective (Stragas & Zeimpekis, 2011). Typical examples include all transfers between refrigerated and frozen warehouses and refrigerated and frozen trucks, door openings, transfers to mixed pallets and/or roll cages, and storage for order compilation.

Benaglia et al. (2024) conducted research on how to improve efficiency by decreasing picking time and staging time in perishables warehousing. They found that strategies based on ABC clustering and SKU correlation rules, or shipping frequency, usually outperform others. Thus, to reduce picking and staging time, random placement in ABC clustering can be a suitable option. This entails that A-class items are placed closest to the docks and C-class items furthest away with a parallel aisle layout. Inside of the areas random storage is implemented.

2.4 Warehouse Design Framework

Various methodologies exist for preparing warehouse configurations, drawing from both literature and practical experience (Baker & Canessa, 2009; Dissanayake & Rupasinghe, 2021). Baker and Canessa (2009) outline an eleven-step framework, synthesizing insights from existing research and industry practices to offer a systematic approach to warehouse configuration. Similarly, Rushton et al. (2014) delve into the intricacies of modern warehouse design, breaking down the process into thirteen steps. They emphasize the iterative nature of these steps, noting that decisions made at later stages may necessitate revisiting earlier steps.

Dissanayake and Thashika (2021) contribute to this discourse by presenting a warehouse configuration framework informed by practitioner insights, consisting of eight iterative steps. Gu et al. (2010) further elaborate on the iterative nature and interconnectedness of design decisions in warehouse configuration, delineating six general steps. The iterative nature of these approaches underscores the complexity and dynamic nature of warehouse configuration, where decisions are interlinked and often revisited throughout the design process. A summarised overview of these steps, suggested by various literature sources, is presented in Table 2.9 on the following page.

Upon review, it becomes apparent that there are notable similarities among the approaches outlined. The initial common step involves defining the warehouse requirements and gathering pertinent data. This entails delineating factors such as warehouse roles, throughput levels, and storage capacity requirements and constraints, as these elements significantly influence subsequent configurational decisions (Rushton, et al., 2014). In this thesis this step begins with understanding the current situation and identifying contextual factors. According to Richards (2018) appropriate data to collect is, among other, SKU characteristics and order frequency. To analyse the data flow charts and activity profiling can be useful. (Baker & Canessa, 2009)

Table 2.9 Step by step guides for warehouse design found in existing literature.

Baker & Canessa (2009)	**Dissanayake & Rupasinghe** (2021)	**Gu et al.** (2010)	**Rushton et al.** (2014)	**Richards** (2018)
Define system requirements	Overall objective definition	Overall structure	Define business requirements and	ABC analysis
Define and obtain data	Selection and specification	Sizing and dimensioning	Define and obtain data	Department layout
Analyse data	Solution generation of systems	Department layout	Formulate a planning base	Decide on appropriate handling equipment
Establish unit loads to be used	Solution with process specification and resource allocation	Equipment selection	Define the operational principles	Install storage systems
Determine operating processes and methods	Solution selection and validation through simulation	Operation strategy	Evaluate equipment types	Deciding on which picking system to use
Consider possible equipment types and characteristics	Warehouse simulation	Performance evaluation	Prepare internal and external layouts	
Calculate equipment capacities and quantities	Warehouse optimisation		Set high level procedures and information system requirements	
Define services and ancillary operations	Warehouse operation		Evaluate design flexibility	
Prepare possible layout	Evaluate and assess		Calculate equipment quantities	
Evaluate and assess			Calculate staffing levels	
Identify the preferred design			Calculate capital and operating costs	
			Evaluate against business requirements and design constraints	
			Finalise the preferred design	

Subsequently, a shared step involves defining both the functional and technical requirements of the warehouse. This encompasses determining the inventory levels the warehouse should accommodate for and establishing a detailed operational configuration (Baker & Canessa, 2009). The technical requirements entail specifying the handling and storage equipment, as well as outlining the requirements for the WMS (Gu, et al., 2010). The operational principles concern for example determining picking method and lane depth of the warehouse (Rushton, et al., 2014). According to Baker and Canessa (2009), regular tools used during this process are spreadsheet models and decision trees.

The final step across these approaches involves generating various layouts and evaluating their performance. This evaluation entails ensuring that business requirements and design constraints are met (Rushton, et al., 2014). It is crucial to recognize, as suggested in the literature, that this process should be viewed as iterative, allowing for refinement and optimization over successive iterations.

3 METHODOLOGY

This chapter aims to present and discuss the methodology used to fulfil the purpose of the thesis. The outline of the chapter is presented in Figure 3.1 below. Initially, the chosen research strategy is presented and argued for, followed by a description of the research process. Thereafter, the methods used for data collection, including literature review and empirical data collection, are presented. Next, the approach used to analyse the collected data is described and discussed. Finally, it is discussed how the research quality of this thesis will be upheld.

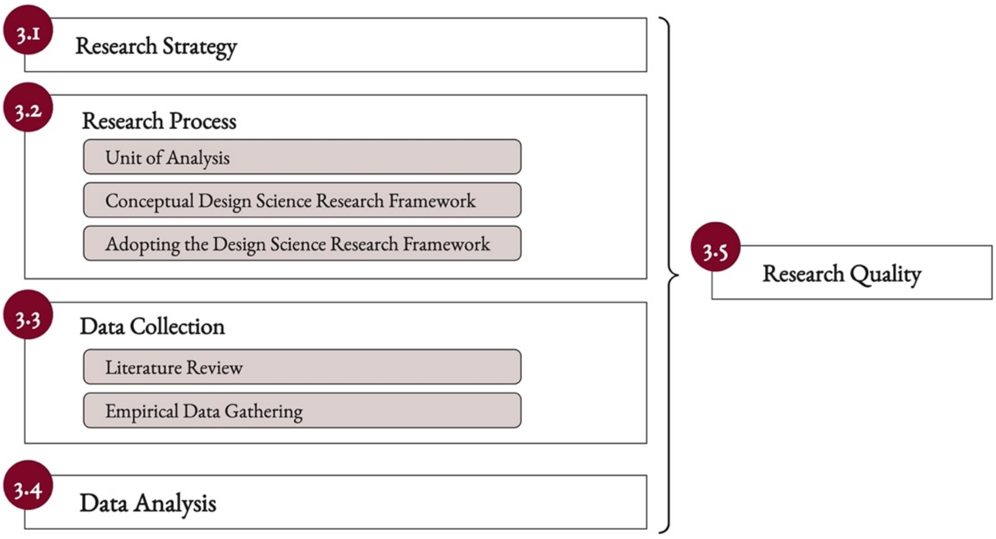


Figure 3.1 Outline of the methodology chapter.

3.1 Research Strategy

A design science (DS) research strategy is an approach aimed primarily at discovery and problem-solving where the process of "exploration through design" is emphasised, contrary to accumulation of theoretical knowledge (Holmström, et al., 2009). DS research is suitable to design and implement actions, processes, or systems to achieve desired outcomes in practice and is driven by real-world operation management problems and opportunities (van Aken, et al., 2016). The desired output from DS research is an artefact, which has been designed to solve the problem at hand (Dresch, et al., 2014). In the context of DS, artefacts are considered man-made and can be characterised based on differences in functions, goals, and adaptation (Op. cit).

Due to the nature of the thesis purpose and objectives, with its starting point in a practical problem, a DS research strategy was deemed appropriate. The choice of research strategy is also supported by the fact that it can be performed both in an academic environment, as well as in an organisational context (Dresch, et al., 2014). Additionally, as stated by Kembro et al. (2022), the DS approach is gaining popularity in research within the fields supply chain and operations management. However, despite choosing a defined strategy it should not viewed as a set of strict rules, but instead guidelines to be used to fulfil the purpose (Saunders, et al., 2009).

Dresch et al. (2014) highlight the main differences and similarities between the following three research methods; (1) DS research, (2) case study, and (3) action research. Two significant differences are related to the objectives and the evaluation of results. For case studies and action research the objective is generally to explore, describe, explain and/or predict focusing on a specific situation. In contrast, the objective of DS research is to design and develop artefacts that enable satisfactory solutions to practical problems and have the potential to generalise the knowledge. For case studies and action research results are evaluated through comparison against theory, while e.g. applications, simulations and/or experiments are used to evaluate the results generated from DS research. Even though the different research methods are similar in some ways, these differences constitute deciding factors and motivate the choice of a DS research strategy for the thesis.

Holmstöm et al. (2009) describes the recurring challenge of making academic research relevant to practitioners where DS, with its exploratory approach, is proposed as a tool to bridge practice to theory. Additionally, DS is often suggested as a possible solution to the criticism that has been directed at traditional sciences. The criticism includes statements that traditional sciences are not dedicated to the design or study of systems that do not yet exist (March & Smith, 1995; Simon, 1996; van Aken, 2004; van Aken, 2005), and that there is a lack of relevance of research conducted exclusively under the traditional science paradigms (Romme, 2003; van Aken, 2004; van Aken, 2005).

Despite the advantages mentioned in comparison to traditional sciences, the research based on DS still faces issues. A key issue for DS research within the field of operation management is the need to deal with social components (van Aken, et al., 2016). In general, operation management systems have both technical and social components, but to varying degrees. For example, a fully automated warehouse can be treated as a technical system due to minimal social components. On the contrary social components needs to be acknowledged in a more manually operated warehouse. For systems where the social components are more prominent, they are necessary to consider ensuring research quality.

3.2 Research Process

This subchapter consists of a description of how the conceptual research framework has been developed based on proposed and formalised methods in existing literature. This is followed by a description of how the framework is adopted to this thesis.

3.2.1 Unit of Analysis

According to Yin (2018) the unit of analysis is important for a research project to get a clear view of how data should be collected and analysed. The purpose of this master thesis is to design a new warehouse configuration for Company Pie's centralised facility for perishable goods, considering accurate contextual factors. Therefore, the unit of analysis was "contextual factors and their influence on warehouse configuration in a DC for perishable goods".

3.2.2 Conceptual Design Science Research Framework

Based on proposed and formalised methods for conducting DS research in existing literature a research process was formed. The research process for the thesis is outlined in Figure 3.2. It is a conceptual framework consisting of seven elements which have been selected to suit the thesis purpose and are based on the main elements for DS research according to Dresch et al. (2014) and March and Storey (2008); (1) identify problem, (2) data collection and analysis, (3) suggest solution(s), (4) development, (5) evaluation and implementation, (6) value addition, and (7) communicate results.

Additionally, the elements are divided into four main phases, adopted from the framework proposed by Romme and Dimov (2021). Their framework connects science, which retrospectively explains the world as it is, and design, which prospectively envision and create a future state of the world and includes the following four activities; (1) framing, (2) creating, (3) validating, and (4) theorising, where the first two activities relate to the design element and the latter two relate to the science element.

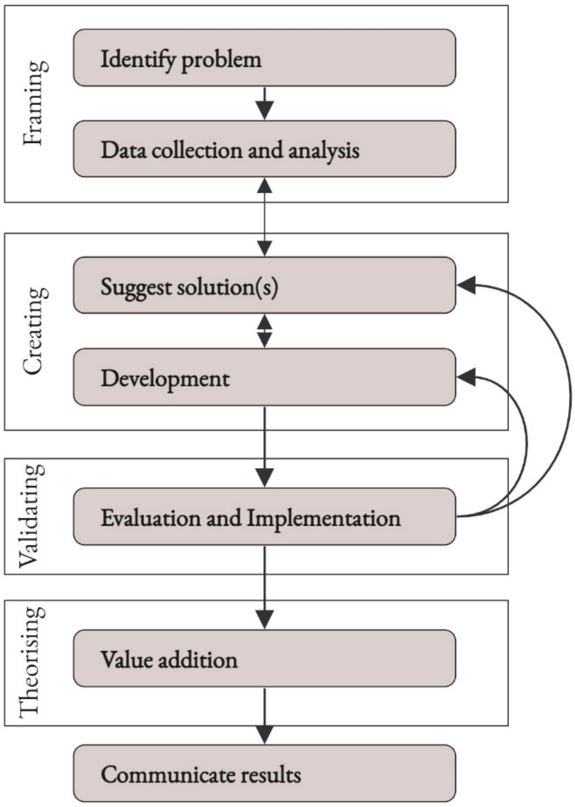


Figure 3.2 Design science framework used in the thesis based on the framework proposed by Romme and Dimov (2021) and the main elements according to Dresch et al. (2014) and March and Storey (2008).

3.2.3 Adopting the Design Science Research Framework

The research methodology originates from the seven elements presented in Figure 3.2 and was utilised when designing the artefact to solve the problem at hand, which in this thesis was to develop a warehouse configuration for a new facility. For a summary of how the method elements was adopted to the thesis, see Figure 3.3.

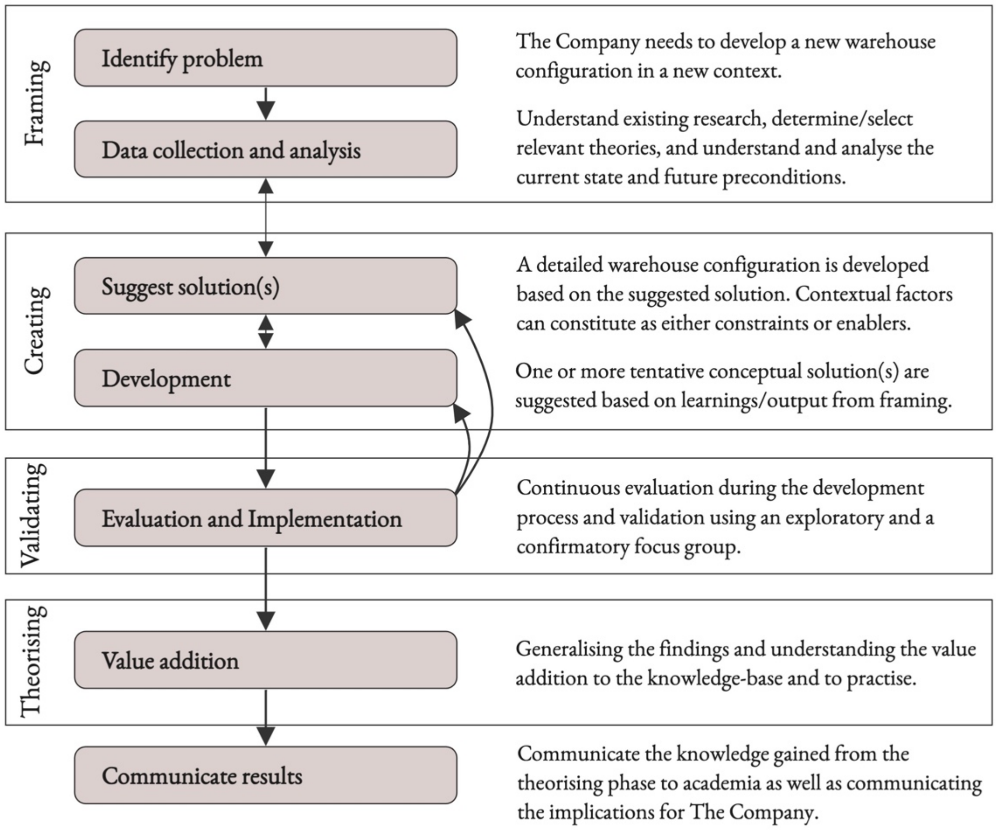


Figure 3.3 Adopting the design science framework for the thesis research.

The first phase is framing of the business problem. The first (1) element is to identify and clearly describe a relevant organisational problem. The problem which is the focus of the thesis is presented in section 1.3 *Problem Statement* and can be summarised as the challenge to implement a new warehouse configuration in a new context. The second (2) element is data collection and analysis. The purpose of this element is to synthesise existing research on the topic, select relevant theory, and understand and analyse the current state in Company Pie's existing facilities and future preconditions in the new DC facility. How the data collection and analysis will be performed is described more in detail in the two following subchapters 3.3 *Data Collection* and *3.4 Data Analysis*. Relevant theory is presented in chapter 2 *Frame of Reference.*

The second phase is to create the artefact and includes the third and fourth element in the framework; (3) suggest solution(s) and (4) develop. Initially, one or more tentative conceptual solution(s) are suggested based on learnings from phase one. Thereafter, the warehouse configuration is developed. During the development it is essential to consider the contextual factors since they may constrain or enable the solution.

The third phase is to validate the developed artefact and is done through (5) evaluation and implementation. The artefact was evaluated by both one exploratory and one confirmatory focus group (Tremblay, et al., 2010). An exploratory focus group was important for interim evaluations and can generate improvements in the artefact. In this focus group an initial artefact was introduced together with three main discussion points including benefits and disadvantages of short versus long side handling of pallets, sectioning the DC into picking zones and how to approach the expected growth in the best way. For more details see Appendix III. A confirmatory focus group was useful when the artefact was ready to be tested in the field since it can confirm its utility and usefulness. In this thesis the confirmatory focus group refers to the final presentation conducted for Company Pie in which the artefact is presented. In Table 3.1 an overview of the focus groups can be found. The participants of the focus groups were chosen based on warehousing and company experience and included people both from the management team as well as people with more operational experience in the DCs. This ensured a multifaceted discussion including different perspectives. However, due to the confidential nature of the project at Company Pie the number of possible participants was limited. The creation and validation phases are part of an iterative process and might require a new solution(s) to be suggested and developed after continuous evaluation to end up with a suitable and satisfactory warehouse configuration. This is referred to as the problem-solving cycle which is illustrated through rounded arrows taking the researcher back to phase three if the develop artefact is lacking in either adaptation to context or performance.

Table 3.1 An overview of the focus groups and their purpose.

Type	Participants	Date	Duration	Purpose
Exploratory focus group	Warehouse Manager x2, Chief Operating Officer, Business Development Director, and Project manager for DC initiative	2024-04-24	2 h	Evaluate interim artefact and explore developments to configuration
Confirmatory focus group	Warehouse Manager x2, Business Development Director, and Project manager for DC initiative	2024-06-03	1 h	Present final artefact and confirm its use in practice

The fourth phase is theorising which refers to generalising the findings and (6) understanding the value addition to the knowledgebase and to practise. The last element is to communicate the knowledge gained from the theorising phase to academia as well as communicating the implications for Company Pie. This includes a recommended warehouse configuration design with a suitable level of automation and tangible estimation of expected performance regarding picking efficiency and required number of full-time employees.

3.3 Data Collection

This subchapter describes the approach for data collection in this research. It is crucial to understand what kind of data is needed to fulfil the research objectives. In accordance with Dresch et al. (2014), both qualitative and quantitative data was be collected. This subchapter will start with describing how the literature review was conducted and move into how empirical data was collected.

3.3.1 Literature Review

A literature review was conducted to gather information in the first framing phase of the thesis research. Literature reviews are secondary studies used to map, critically evaluate, and find relevant primary studies on a specific research topic (Dresch, et al., 2014). According to Dresch et al. (2014) the literature review is essential to access existing knowledge necessary to develop the artefact and, consequently, solve the problem. The purpose of a literature review in this thesis was as a means of building theoretical ground for fulfilling the purpose of this research.

There is no single method for conducting a literature review (Dresch, et al., 2014). However, the core of any literature review is to search, select and evaluate the quality of the studies to be considered (Dresch, et al., 2014). Sources were searched for primarily through the databases Web of Science and Google Scholar. The search was conducted by searching for keywords such as: "warehouse configuration", "storing perishable goods", "influence of context on warehousing". Furthermore, books regarding warehouse management were borrowed from the faculty library. In line with Dresch et al. (2014) each reference found in this study was screened by a quick read through to identify the subject of the study and to decide whether it helps building a theoretical ground for the research analysis.

3.3.2 Empirical Data Gathering

The empirical data gathering consists of both qualitative and quantitative data collection (Dresch, et al., 2014). Producing valid and reliable results requires determining what information to collect (Albers, 2017).

Quantitative Data

Quantitative data consists of variables that can be quantified in terms of frequency, percentage of cases or proportion (Cramer, 2003). This means that quantitative data can be viewed as numbers, for example the number of SKUs in a warehouse. It is hard to judge the effectiveness of a warehouse based on only daily observations. According to Bartholdi III and Hackman (2019), the history of customer orders together with a map of the warehouse can give a more complete picture.

To understand any warehouse, a necessary first step is to understand the customer orders which drive the system (Bartholdi III & Hackman, 2019). Warehouse activity profiling is the measurement and analysis of warehouse activity. Bartholdi III and Hackman (2019) states that the key qualitative data points to collect for an activity profiling are data pertaining to each SKU, data pertaining to each customer order, and data pertaining to locations within the warehouse. Examples of data that are relevant to collect are presented in Table 3.2 below. The data was requested according to Appendix VI, however the data provided by Company Pie represented a shorter period than initially desired.

Table 3.2 Summary of quantitative data relevant for the purpose of the research based on Bartholdi III and Hackman (2019) and Rushton et al. (2014)

Type of data	Description	Purpose
Product/SKU	Weight, height, fragility, temperature requirements, quantity per pallet	Determine storage and handling equipment requirements
Inventory profile	Quantity throughput, value throughput, inventory turn, seasonality, #pallets as is	Understand volumes and inventory requirements in the current and new DC and seasonality
Pick profile	Order lines, pick lines per order line, number of order lines for each SKU	Understand patterns of work
Order frequency	Time of day, month, year	Understand when activities occur.
Storage locations	Drawing of new building dimensions, unit load types and profiles	Understand warehouse logic and create a heatmap
Equipment	Equipment specification and supplier	Understand functionality and requirements of handling equipment

Qualitative Data

Qualitative data focuses on people's experiences and the meanings they place on processes and structures in their normal social setting. Qualitative data provides a more holistic view of the participants perception of certain situations (Hollowy et al., 2000). Thus, it is particularly valuable for researchers seeking to explore real organisational goals, and linkages and processes in organisations (Op. cit.).

In the case of this thesis, qualitative data consists of observations and interviews at Company Pie. Table 3.3 shows all observations conducted in this thesis research. Observations were conducted to map the warehouse operations in the current DC and to observe the new DC. This contributed to the achievement of the first objective; understanding the operations at the current DC. It also helped with the second and third objective of identifying challenges and contextual factors for the new warehouse. To make systematic observations of operations within the warehouse, an observation protocol was kept. The purpose of such a protocol is to minimise the variations that arise from individual perceptions (Denscombe, 2010). An advantage of conducting observations at Company Pie is that it provides a direct data collection. According to Denscombe (2010) it gives an insight into what people actually do, in contrast to what they might say they do. It is also useful for collecting substantial amounts of data in a short time span, which is useful given the time constraint of this research.

Table 3.3 The conducted observations in PDC and NDC and their purpose.

Observation	Date	Duration	Purpose
Current PDC	2024-02-12	3 h	Understand part of the context of the research.
New DC	2024-03-01	2 h	Understand context.
Replenishment current PDC	2024-03-18	10 min	Observe the replenishment process.

Beside observations, interviews were also conducted as a part of the qualitative data collection. Interviews in this research are done to fill gaps between observations and quantitative data to get a more nuanced understanding of the situation. According to Denscombe (2010) interviews can be used to gain insight into people's opinions and experiences. This is important to understand the present challenges in the warehouse configuration.

Semi-structured interviews give the advantage of flexibility as a researcher in terms of the order in which topics are considered. This allows the interviewee to develop and speak more freely, while simultaneously having a clear list of questions to answer and topics to address (Denscombe, 2010). A disadvantage of conducting interviews is that they are often time consuming to both conduct and analyse. In this thesis semi-structured interviews were conducted to explore interviewees perceptions. However, three of the interviews conducted were structured interviews with few questions due to a limitation in time with the interviewees. For a visualisation of the interview schedule, see Table 3.4 below.

Table 3.4 An overview of interviews conducted together with a description of their purpose

Type	Interviewee	Date	Duration	Purpose
Semi-structured	Warehouse manager	2024-03-18	2 h	Understand the WH operations and gain insights on inefficiencies in the current warehouse.
Structured	Inbound operator	2024-03-18	15 min	Gain insights on challenges in the current warehouse.
Structured	Frozen operator	2024-03-18	15 min	Gain insights on challenges in the current warehouse.
Structured	Ambient picking operator	2024-03-18	15 min	Gain insights on challenges in the current warehouse.
Semi-structured	Business Development Director and interim manager of warehouse and distribution	2024-03-12	2 h	Understand the warehouse operations and gain insights on differences in warehouse operations in the company group
Semi-structured	Project manager of the new distribution centre initiative	2024-04-16	1 h	Understand how AGVs will operate and to which extent the physical layout must be adapted to them

3.4 Data Analysis

The empirical data gathered in the research requires analysis to draw conclusions (Albers, 2017). Data analysis is the key to uncovering patterns, trends, and relationships within the empirical data. The data analysis was conducted to address the research objectives of this study. By integrating qualitative and quantitative findings, a richer story that captures the nuances of the research was created.

Part of the data analysis in this thesis was conducted using techniques from the case study research method. One of the techniques used for the data analysis was pattern matching. Pattern matching logic compares the empirically collected data to the predictions made in the literature review conducted in the beginning of the research (Yin, 2014). If the empirical and predicted patterns are similar, it can help strengthen the internal validity (Yin, 2014). In this research, pattern matching was used in two steps, first to synthesise the literature review and then to analyse the qualitative and quantitative data.

To synthesise the literature review, Dresch et al. (2014) argues that the best synthetisation technique to use is ecological triangulation. The main objective of this technique is to answer the question "What type of artefact causes what type of results under which heuristics?". In the case of this research, this meant producing a table synthesising common themes and solutions in a table to display the different patterns visible within the literature.

The data analysis of qualitative and quantitative data differs from each other. Finding patterns in interviews and observations was done by matching what different interviewees answered and what was observed. Mismatches in answers and observation were an indication of either role related challenges or misalignment between policy and reality. When analysing quantitative data, data was collected, validated, analysed and then the findings were confirmed by comparison to insights provided by Company Pie. Once the data was validated it was sorted into spreadsheets where exploratory data analysis was performed. This was followed by data visualization using graphs to show statistical correlations and to identify order and product characteristics based on order size, workload quantity, and product size.

Statistical analysis is used to reveal patterns in data, for example, in the way product moves through the warehouse (Bartholdi III & Hackman, 2019). The data analysis is done by visualising the data to identify patterns, for example using distributions, graphs or heatmaps. The statistical analysis was conducted to, among other things, visualise the number of picks per order and to visualise growth in number of pallets in the NDC.

To analyse quantitative data from the warehouse activity profiling, an ABC analysis and statistical analysis was conducted. In the case of designing a new warehouse configuration, the patterns of customer order and how this determines the workload at the facility must be analysed (Bartholdi III & Hackman, 2019). According to Richards (2018) a full ABC analysis of stock movement and stock held in place should be done before configuring a warehouse. An ABC analysis is used to visualise which SKUs in the warehouse matter, that is, which SKUs account for the most activity. It is derived from Pareto's law and the 80/20 rule that states that 80 percent of effect comes from 20 percent of causes (Richards, 2018).

Pareto's law is used when categorizing items into 'A', 'B', and 'C' classification. This helps reveal the economic terrain of the warehouse (Bartholdi III & Hackman, 2019). An ABC analysis of the frequency of picks was conducted by sorting the 20 percent of SKUs accounting för 80 percent of the picks into A and B classes. The remaining 80 percent of SKUs were classified as C.

The analysis of the contextual factors influencing the configuration of the studied warehouse was conducted inspired by the framework for qualitative analysis from Kembro and Norrman (2021). To identify which contextual factors affected the configurational decision, the summarising tables from the "Warehouse Configuration" chapter in "Frame of Reference" were transcribed onto paper, highlighting key contextual factors relevant to storage and picking operations. The configurations from these tables were then logically positioned in the context matrix according to Figure 3.4. Subsequently, empirical findings from data collection were analysed to place Company Pie's NDC within the matrixes. In the illustrate figure below, the most suitable configuration for the studied system would be Configuration C based on Contextual factor A and B. Initially, each researcher conducted this analysis independently, followed by collaborative discussions to reach a common conclusion.

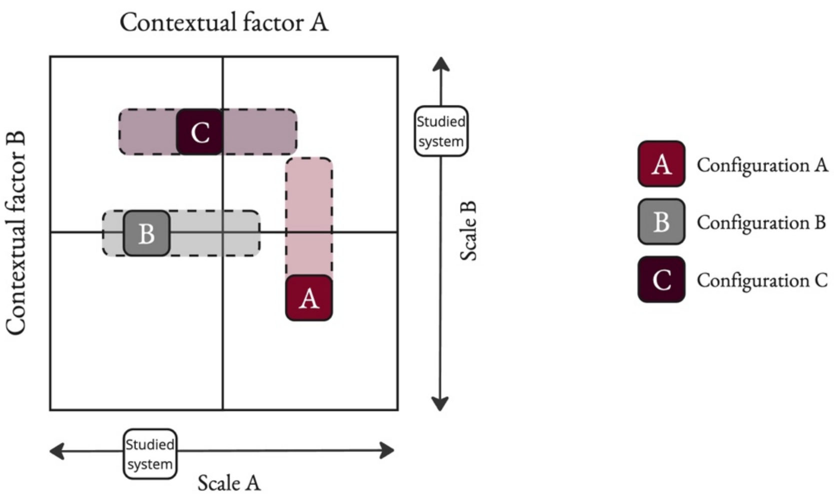


Figure 3.4 Conceptual framework for qualitative analysis of contextual factors and configurations, inspired by Kembro and Norrman (2021). In the figure the configurations are arbitrarily placed.

3.5 Framework for Data Collection and Analysis

Below, Figure 3.5 on the following page, displays the framework used for data collection and analysis in the thesis, where the various tools and frameworks presented in the frame of reference are placed in connection with the corresponding topic. The framework displays the structure of the research and provides an overview of the type of empirical data that was required, as well as what analysis was performed, and when. It also shows the interlinking relationship between the research objectives and the iterative nature of warehouse configuration design.

In line with RO1, the current state at PDC, RDC, and NDC was described to be able to analyse contextual factors influencing the configuration in NDC. The constraints in the NDC are also presented. Identifying and analysing contextual factors is part of RO2 and was done by applying tools presented in this frame of reference part of the thesis with empirical findings. Finally, in line with RO3, the artefact, which was a physical layout for the NDC together with a recommendation of configuration of picking policy, strategy, and storage allocation, was developed. By following the structure of research objectives the purpose, designing a new warehouse configuration for Company Pie considering accurate contextual factors, was fulfilled.

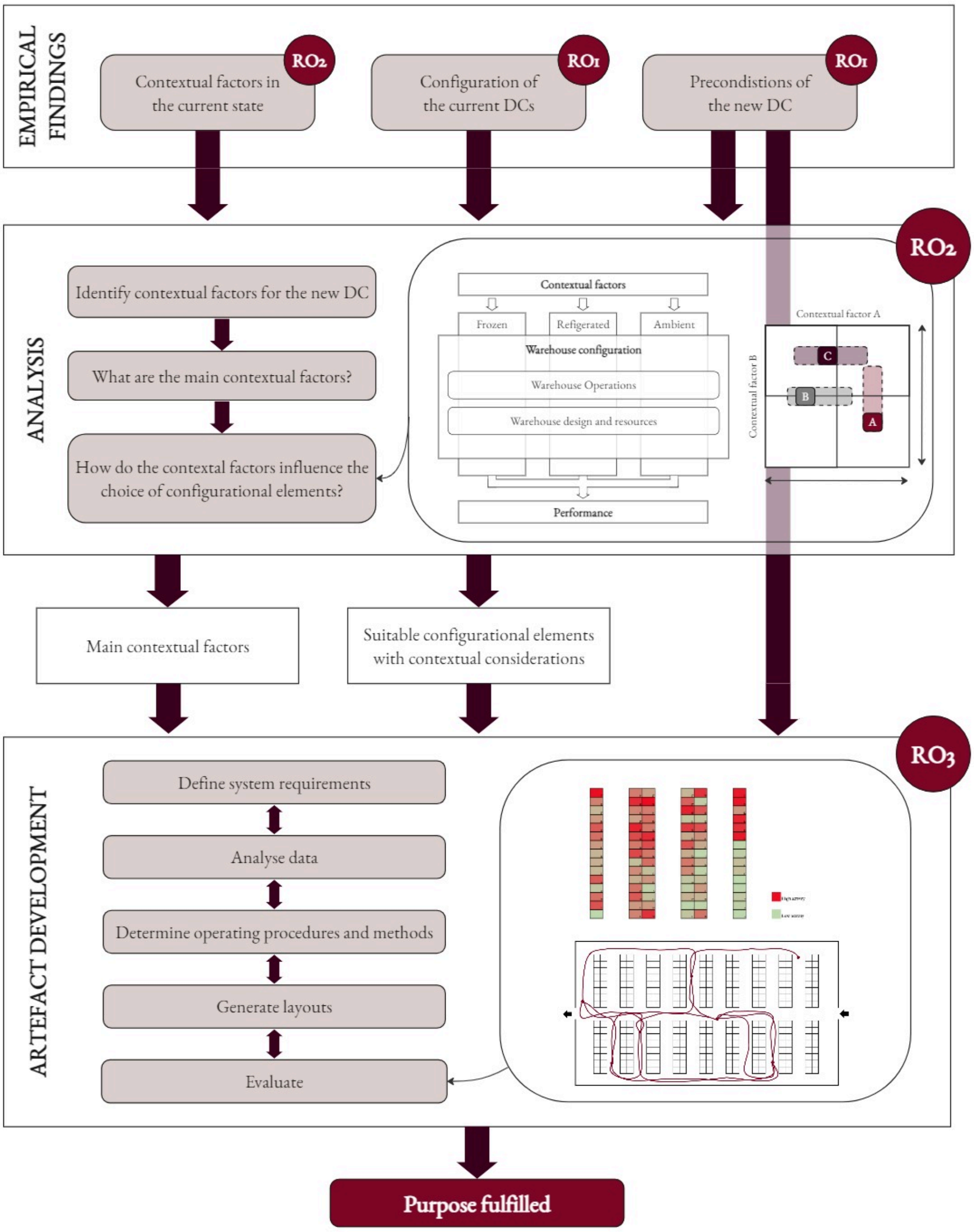


Figure 3.5 Framework for data collection and analysis.

3.6 Research Quality

DS research combines environment, the people, organization, and technology, with the theoretical and methodological knowledge base (Havner, et al., 2004). A convincing theory that is not useful for the environment provides as little to theory as an artefact that does not solve a problem. To improve research quality, there are two aspects to focus on according to Havner et al. (2004). Rigour addresses the way in which the research is conducted, and relevance is related to acquiring knowledge on and understand what enables the development and implementation of an artefact that solves an unsolved and important business problem. These two factors need to be balanced since an over emphasis on rigour has often resulted in a lowering of relevance (Havner, et al., 2004). The approach used to achieve research quality in this thesis is visualised in Table 3.5 below, and further developed in the following subsections.

Table 3.5 An overview of this thesis validity, reliability and relevance inspired by (Yin, 2018), (Dresch, et al., 2014) and (Bans-Akutey & Tiimub, 2021)

Research Process		**Data Collection**		**Data Analysis**
External validity	**Relevance**	**Construct validity**	**Reliability**	**Internal validity**
Use theory in design science study. Discussion about replication logic	Results presented to knowledgeable practitioners	Use multiple sources of evidence. Terminology explained to informants. Included multiple informants representing different internal functions to triangulate responses.	Standardised interview protocol used for data collection. Maintain a chain of evidence	Do pattern matching. Address rival explanations. Building insights through data driven reflections

DS research requires rigorous methods in the construction and evaluation of the artefact (Havner, et al., 2004). In DS research, rigour is derived from the effective use of the knowledge base to select appropriate techniques to develop an artefact and then select the appropriate means to evaluate the artefact (Havner, et al., 2004). In selecting the appropriate techniques validity and reliability must be considered. The principal aim is to determine how well an artefact works, and theorising about why the artefact works is not as important. Therefore, claims about artefacts are usually dependent on performance metrics and these must constantly be assessed to ensure their appropriateness (Havner, et al., 2004).

To construct validity in this report, multiple sources were used to conduct the research. Multiple sources were used in both data collection and in the literature review. Data was collected through multiple channels, interviews, and observations, to get a variety of perspectives. Afterwards, the validity of the information provided was reviewed through checks with stakeholders at Company Pie to make sure that the provided data was correctly interpreted. The interim evaluation of the artefact also ensures the validity and relevance of the research.

For quantitative data, once the data was collected it was validated through several steps. The first step was to check the data integrity to ensure that all required fields were filled and that there were no unexpected gaps. The second step that was performed was to validate the format and type to confirm that the data was in a correct format and data type as required. This included ensuring consistent date format and that numerical values were within the correct range. Next was accuracy verification where data entities were cross checked against the master data. As a fifth and last step any duplicates and returns where removed.

Another technique that was used to increase rigor of the research was multiple triangulations. Multiple triangulations entail that two or more triangulation types are used in the research (Bans-Akutey & Tiimub, 2021). For this study data triangulation, which is the use of several data sources in a study, was combined with investigator triangulation, which is the use of different researchers, to improve rigor. The data triangulation included finding support for certain statements made by interviewees in the quantitative data that had been collected. Investigator triangulation was for instance utilised when making the distinction between main and miscellaneous contextual factors, as well as when the different configurations were positioned in the context matrix. Although research triangulation requires more resources from the researcher, benefits include improved credibility and validity as well as more comprehension of the concept studied (Bans-Akutey & Tiimub, 2021). It is also easier to notice inconsistent data using triangulation, therefore, it was deemed appropriate for this research.

According to Dresch et al. (2014), for research following a DS research methodology to be reliable, and therefore replicable, it must follow the elements of the DS method and pay attention to the outputs of each element formalising a research protocol. This protocol should be continuously updated and must show, in detail, all the planned activities and the perceptions and insights that might arise during the execution of these activities. The protocol for the interviews and exploratory focus group can be viewed in Appendix. I, II, and III.

The quality of the literature was assessed according to the two dimensions mentioned by Dresch et al. (2014). The first dimension refers to the quality of conducting the study, that is, whether it was conducted by standards deemed appropriate for the studied topic and if the findings were based on facts and data. The second dimension assesses the relevance of the study to the thesis purpose. This assessment is done prior to the synthesis of the results to ensure the quality of both the research process and the selected primary studies.

4 EMPIRICAL FINDINGS

This chapter presents the empirical findings and describes the current situation at Company Pie and Company Rho based on the conducted interviews and data provided by Company Pie. The numbers presented are anonymised to not reveal any confidential information about Company Pie. The first section describes the contextual factors of the new DC. The second section covers the warehouse configuration of Company Pie's main DC (PDC) and the configuration of Company Rho's DC (RDC). The third and last section describes the preconditions at the new DC facility including automation plans. The outline of the chapter is shown in Figure 4.1.

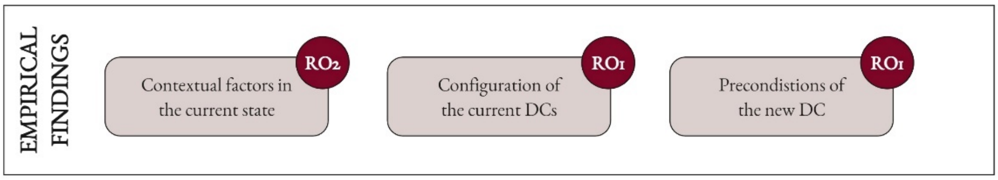


Figure 4.1 Outline of the empirical findings chapter from the framework for data collection and analysis.

4.1 Contextual Considerations

The aim of this subchapter is to describe the identified contextual factors based on the collected data and to categorise them according to the three levels by Eriksson et. al. (2019). The external and internal corporate contextual factors found to impact the current DCs are elaborated on below. Furthermore, the internal DC contextual factors are covered in chapter 4.2 where the current DC configuration is described.

The three DCs which are the focus for the thesis all operate in quite similar contexts since all are part of Company Group Pie. They are all in Sweden, handle perishable goods, use similar or the same suppliers, and partially serve the same customer segments. Due to this the contextual factors will, for the most part, be presented by grouping the three DCs together and when deemed appropriate relevant differences will be highlighted. Looking back at Figure 1.1 showing the transition from a decentralised network to a centralised network the reader is reminded of the role of the DCs in the supply chain network.

4.1.1 External Contextual Factors

The external factors that have been identified include national legislation, customer characteristics, order characteristics, demand profile, and product characteristics.

National Legislation

National legislation permeates all aspects of all DCs. Compliance with Swedish laws mandates adherence to high standards in salaries, work environment, and food safety. The high labour costs drive a push towards automation to maintain efficiency and competitiveness. Ensuring a safe work environment involves addressing challenges such as ensuring ergonomic standards to prevent injuries from heavy lifting and managing temperature variations, particularly in frozen goods handling. Food safety and quality regulations necessitate strict processes and separated temperature zones to prevent contamination and ensure product quality. For this reason, the DCs have separate processes and routines for frozen goods.

Customer Characteristics

Looking at Company Pie and Rho there are many similarities, but also some significant differences, related to customer characteristics. Both companies have all their customers in Sweden, consequently all deliveries are within Sweden. Out of the four customers segments, small-scale businesses, store-in-stores, industrial customers, and restaurants, Company Pie serves the first three and Company Rho serves the latter two. The industrial customers are served by both companies.

There are many different customers that are served from the current DCs. Company Pie is found to have almost 2500 unique customers with frequent deliveries of perishable goods. Depending on the type of customer, their preferences vary. Generally small-scale businesses and restaurants request smaller volumes and smaller packages. This stands in contrast to the industrial customers where the volumes are larger as well as the requested package sizes. There are somewhat varying preferences from customers when it comes to how products with different temperature requirements are mixed in the delivery. For large orders dry and cold items are separated.

In addition to the perishable goods, the DCs also handle non-food products which often are customer specific. It is evident from the interviews that these items generate additional complexity. Furthermore, customers are allowed to place orders at short notice. First a main order is placed, however it is very common with additions. These additions are possible to satisfy until the truck with that order has left the DC.

Demand Profile

To build on the understanding of the characteristics of Company Pie's and Rho's customers, it is relevant to examine how these dynamics are interconnected with the DCs demand profile. Specifically, when it comes to volume, seasonality, or any other variation, as well as growth.

There is a clear difference related to demanded volume for the different customer segments, where customers that are small scale business demand smaller volumes which stands in contrast to large scale industrial customers that demand significantly larger volumes. As the customers are recurring, the same usually applies for their orders as well. However, since the DC handles perishables seasonality is to be expected.

For Company Pie and Rho certain SKUs experience peaks in connection with holidays and the seasons. Although there are no specific campaigns driving demand, products associated with specific seasons, such as summer or winter items, show significant fluctuations. For example, frozen goods may see increased demand during the summer. Despite these seasonal trends, the overall number of pallets handled remains relatively constant throughout the year with a slight increase during the second half of the year, and a small peak before Christmas. Since quantitative data provided by Company Pie was restricted to a year, this finding was also discussed and confirmed in a weekly meeting with the project manager for the DC initiative at Company Pie. The finding suggests that while the specific products in demand shift, the total volume of goods processed by the warehouse does not vary drastically. This can be seen in Figure 4.2 to the left below.

In the weekly order distribution there are notable fluctuations, with Wednesday emerging as the peak day for the number of orders leaving the DCs. This peak is followed by a slight decline in the number of orders on Thursdays and Fridays. This is shown in Figure 4.2 to the right. The weekly pattern can be ascribed to the customer delivery schedule which is partly based on the distance to the different delivery locations, which was highlighted by the warehouse manager in the conducted interview.

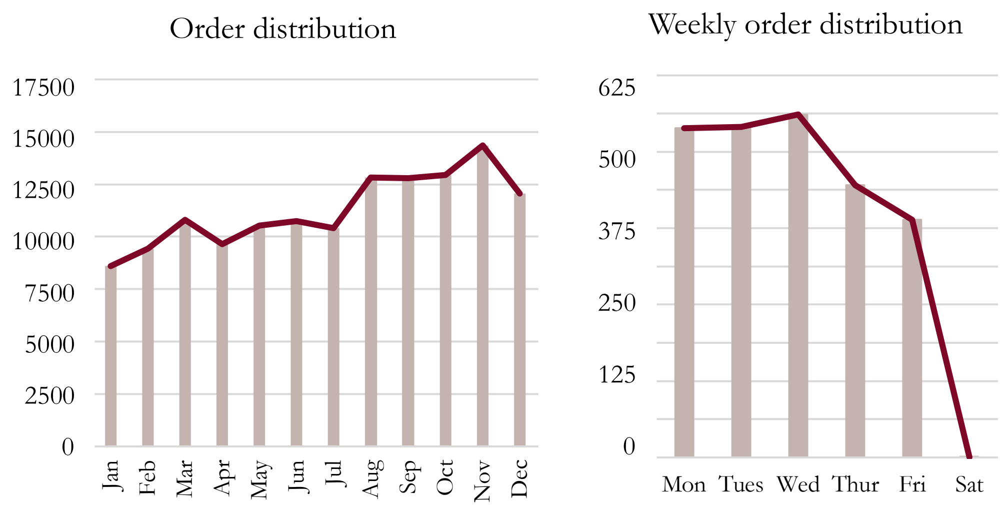


Figure 4.2 Left: Order distribution throughout a year, based on data from 2022 from all three current DCs. Right: Weekly order distribution, based on data from July to December 2022 from all three current DCs.

Order Characteristics

When looking at the customer orders that the DCs receive, it is seen that the DCs handle many orders and that there are significant differences when it comes to size, order structure, and order flow mix. The total number of orders, often referred to as transactions, processed in the three DCs was 135 183 during 2022. This generates an average of about 538 orders each day, for a five-day workweek.

The size of customer orders, regarding number of work lines for each order, has a large variation which can be seen in Figure 4.3. A work line is here referred to as specific task, such as picking, related to a customer order. The number of work lines vary from a minimum of one, which account for about 19 percent of the orders, to a maximum of 177 work lines - which occurs in one order. However, the share of orders with 61 or more work lines only represents 3 percent of the orders. From the data it is also found that 50 percent of the orders have 9 work lines or less. To summarise, the orders vary significantly in size, however, most orders have less than 10 work lines.

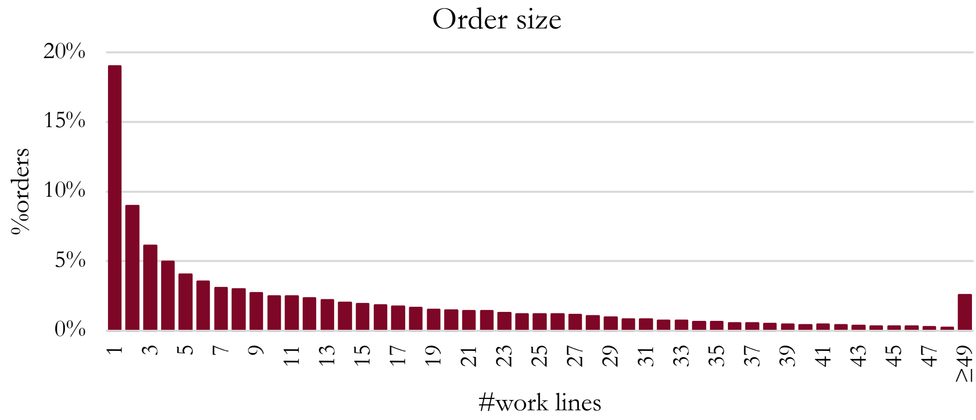


Figure 4.3 Histogram visualising the variation in order size, where the x-axis show the number of work lines and the y-axis indicate the percentage of orders with a particular number of work lines. Based on data from July to December 2022 from all three current DCs.

In addition to variation in size, the orders vary when it comes to what temperature zone the items are stored in. As a result of the sensitive nature of frozen items, as well as the quality and safety requirements, orders containing frozen items are separated into two pick lists which are handled separately in the DCs. Figure 4.4 below shows the order distribution between the three different temperature zones, where the frozen zone is separated from the rest. Approximately one third of the orders includes items that are stored in both the cold and the dry zone. Therefore, these orders require visits to two different temperature zones when picked. While 30 percent of orders only contain items from the dry zone, the corresponding number for the cold zone is only 4 percent.

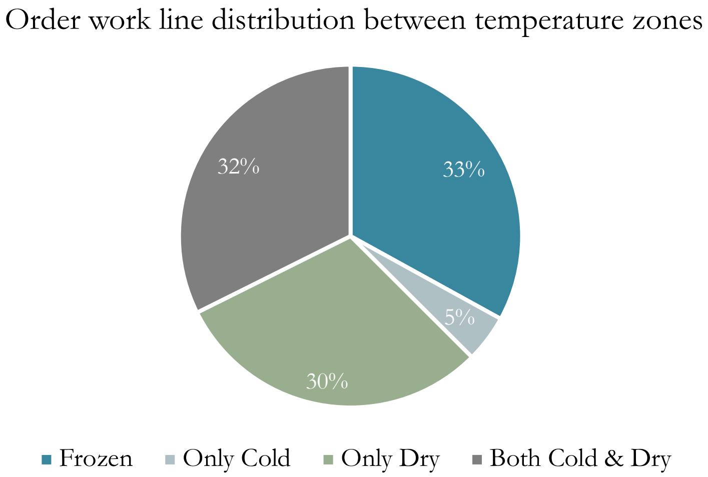


Figure 4.4 Order distribution between the three temperature zones for Company Pie and Rho.

In addition to looking at the number of work lines and the required visits to various temperature zones, it is of relevance to understand the volume or weight of the orders. Figure 4.5 below show the total weight of orders picked in the dry and cold zone as well as in the frozen zone. The weight of the orders is based on the work quantity for each order work line and indicate a significant difference between the zones. Based on the assumption that the maximum weight of a pallet is one thousand kg, at least 3 % of the orders in the dry and cold require more than one full pallet. However, this ratio is most likely higher since pallets are often full before reaching the maximum weight. This stands in contrast to the weight of orders in the frozen zone which are significantly lighter.

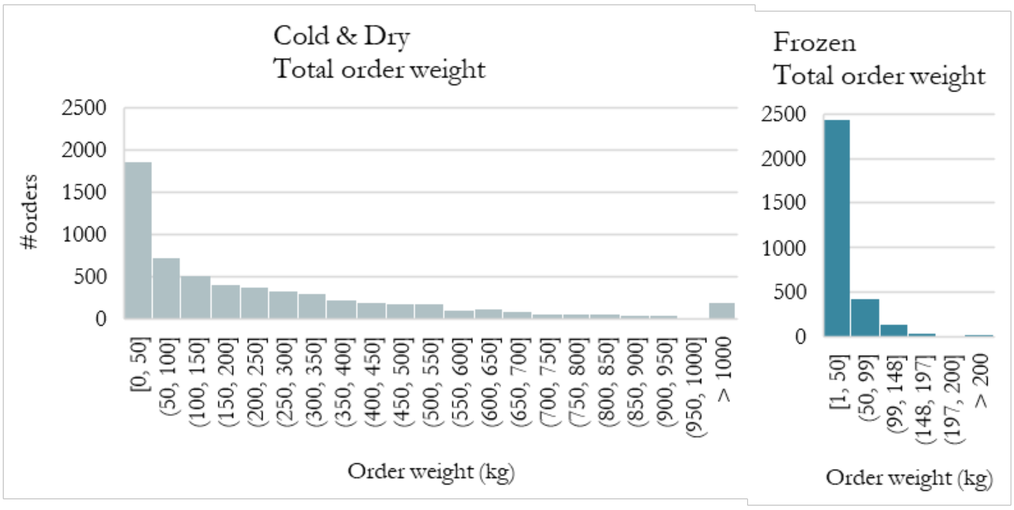


Figure 4.5 Histograms showing the total weight (kg) of the orders, accounting the work quantity for each work line and order. Based on data from Company Pie (not including Company Rho) from November 2022.

Furthermore, Figure 4.6 and Figure 4.7show the relation between work quantity, work lines and weight for orders in the cold and dry zones and the frozen zone, where one bubble represents one order and its size indicates its total weight. Initially we see a significant difference between the cold and dry zone, compared to the frozen zone when it comes to work quantity and work lines, where both are smaller in the frozen zone. Additionally, the number of orders is also smaller in the frozen zone. There is a pattern indicating that for most orders the work quantity will increase with an increased number of work lines. However, there is no strict correlation between the parameters and there are examples of orders with very few different products but with large quantities. By looking at the two bubbles circled with a red dotted line in Figure 4.6 this reasoning is clarified. The larger bubble represents a quite heavy order with a total of around 500 items, but only around

30 different items. This stands in contrast to the smaller bubble, that represents an order that is not as heavy and where the total number of items is about the same as the number of unique items, which in this case is about 60 items.

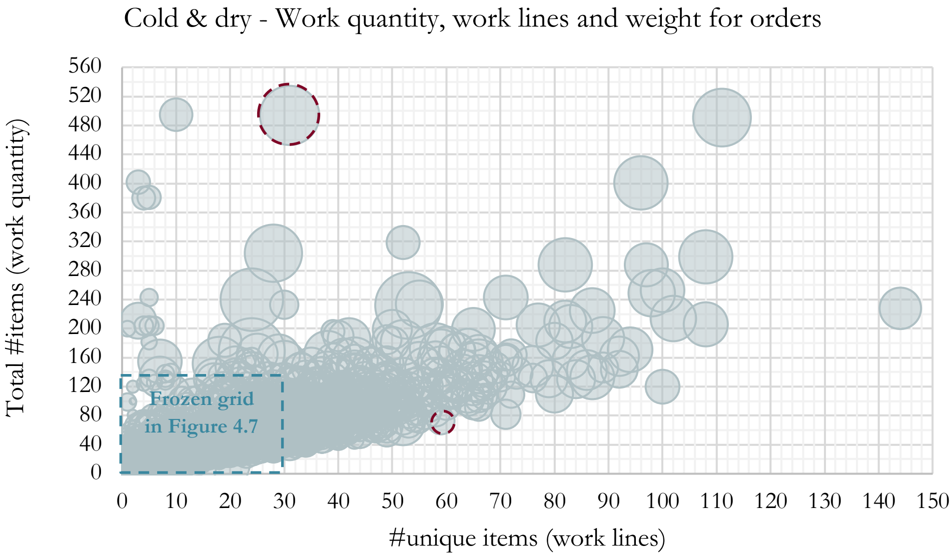


Figure 4.6 The relation between work quantity, work lines and weight for orders in the cold and dry zone where one bubble represents one order, and its size indicates the total weight. Based on data from Company Pie (not including Company Rho) from November 2022.

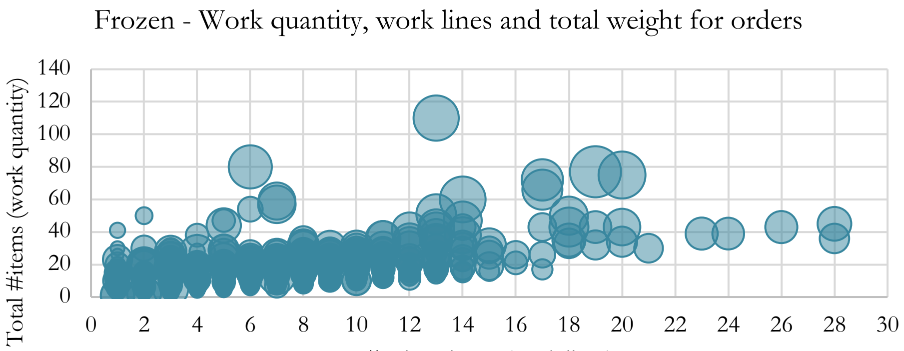


Figure 4.7 The relation between work quantity, work lines, and weight for orders in the frozen zone where one bubble represents one order, and its size indicates the total weight. Based on data from Company Pie (not including Company Rho) from November 2022.

Product Characteristics

The full product range which Company Pie and Rho offer their respective customers includes a variety of product characteristics. Due to the DC handling perishable goods, it is inevitable that product shelf life, and temperature requirements are of high importance. Additionally, Company Pie and Rho put great emphasis on fragility and stackability as well as pick frequency. Due to lack of existing data on product fragility, product weight is used to indicate fragility based on the assumption that low weight products are more fragile than heavier products.

Figure 4.8 below show shelf life and weight for the products where the basis for comparison is the total number of items IDs in the DCs. From the left graph we see it is only in the cold zone there are products with a shelf life of 28 days or less, with a minimum of 7 days. On the contrary, it is only in the dry zone there are products with a shelf life longer than two years. To the right in the figure, we see that the weight of products is quite evenly distributed across the three temperature zones. However, the product weight ranges from 1,25 gram to 1300 kg but with over 80% of the products weighing between one and 25 kg.

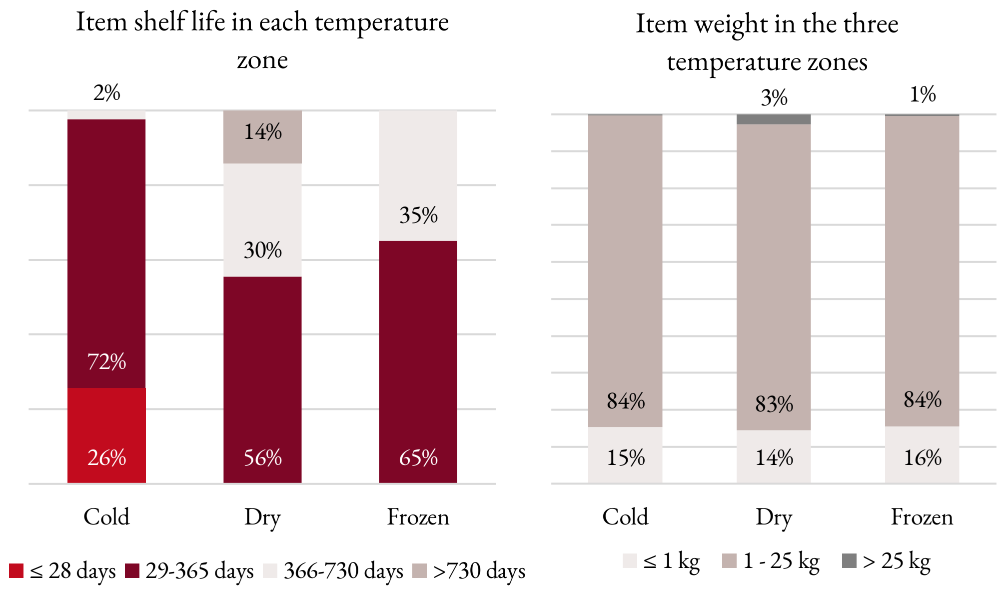


Figure 4.8 Left: The shelf life of the items and how it differs in each temperature zone, based on data from November 2022. Right: The weight of the items and how they are spread out in the temperature zones, based on data from November 2022.

As a result of the demand profile described above in combination with the short shelf life of certain products, the frequency of which items are picked is significant. In Figure 4.9 and Table 4.1 below the results of an ABC analysis are presented. The result shows how there are a small percentage of items standing for a large percentage of the picks. This is especially significant in the cold and in the dry zone. In Table 4.2 is a list of the items with the highest volume in class A in the dry zone.

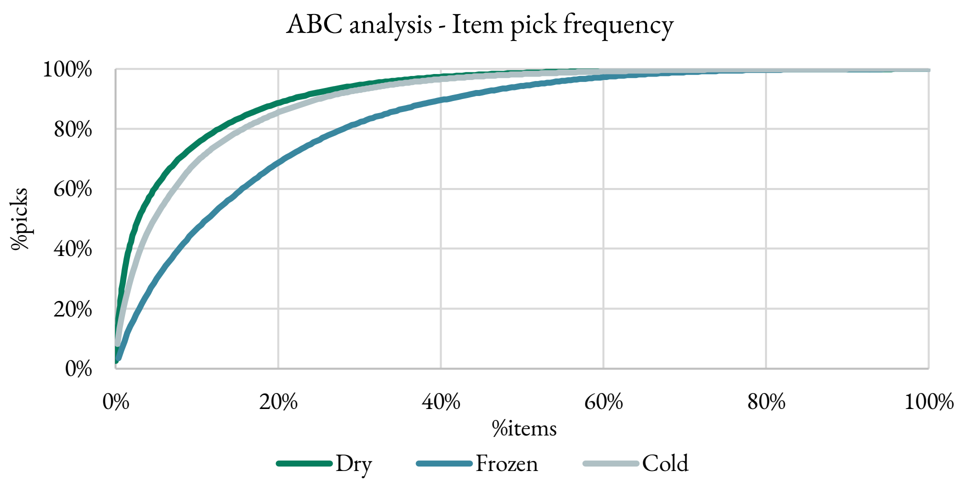


Figure 4.9 An ABC analysis of item pick frequency looking at each temperature zone. Based on data from November 2022 from all three current DCs.

Table 4.1 A more granular table of the ABC analysis from the previous figure. Based on data from November 2022 from all three current DCs.

		Dry		**Frozen**		**Cold**	
Class	%picks	#items	%items	#items	%items	#items	%items
A	40%	74	2%	26.25	8%	15	3%
B	80%	493	11%	69	20%	68	13%
C	>80%	3905	87%	249	72%	448	84%

Table 4.2 Listing the items with the highest volume and in class A in the dry zone. Based on data from November 2022 from all three current DCs.

Storage type	Temperature	Class	#pallets	Item name
Floorstack	Dry	A	134	Product 01
Floorstack	Dry	A	95	Product 02
Single Pallet	Dry	A	119	Product 03
Floorstack	Dry	A	74	Product 04
Single Pallet	Dry	A	304	Product 05
Single Pallet	Dry	A	132	Product 05
Single Pallet	Dry	A	124	Product 06
Single Pallet	Dry	A	116	Product 07

4.1.2 Internal Corporate Contextual Factors

The internal corporate contextual factors that have been identified include corporate strategy, the role of the distribution centre, as well as the product assortment.

The purpose and role of the DCs is to consolidate items from various suppliers, provide customised items, and provide frequent and timely deliveries based on customer preference. The closeness to customers is of great importance, hence the local placement. An important part of the company strategy is growth, specifically through acquisitions. In Figure 4.10 below the ten-year growth plan can be seen. It has been calculated based on numbers provided by Company Pie about the company growth, and then translated to show the average number of pallets in stock in the DC in November for the corresponding year. Note that a frozen item referred to as Product F in the figure, is separated from the rest of the frozen items due to it being a temporary product which is not a part of the regular product assortment.

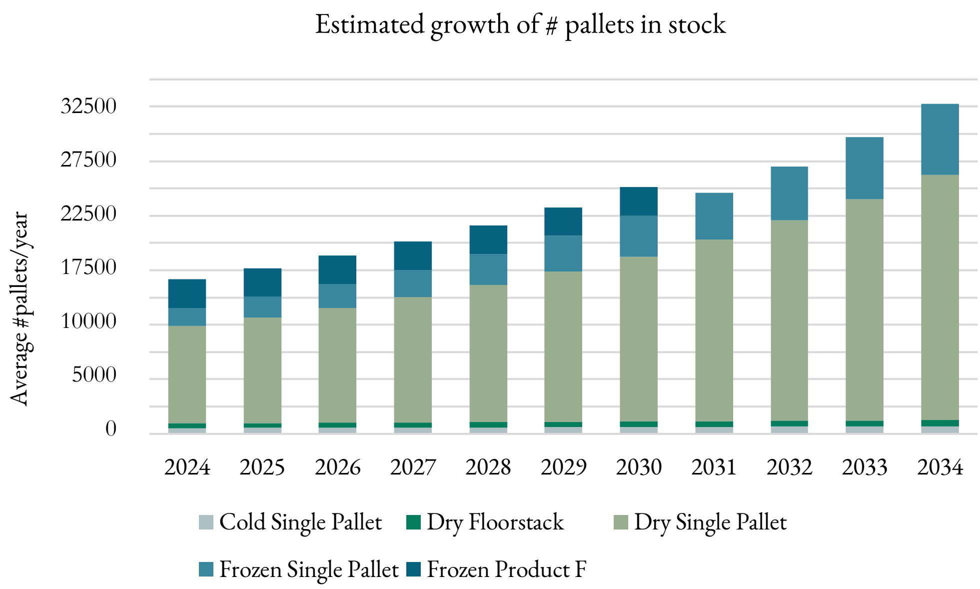


Figure 4.10 Estimated growth of number of pallets in stock between the years 2024 and 2034.

Furthermore, the total number of unique items at Company Pie is 5813 and 2419 at Company Rho which makes a total of 8232 unique items. A large majority of these items are found in the dry zone (includes non-foods) which can be seen in Figure 4.11 below.

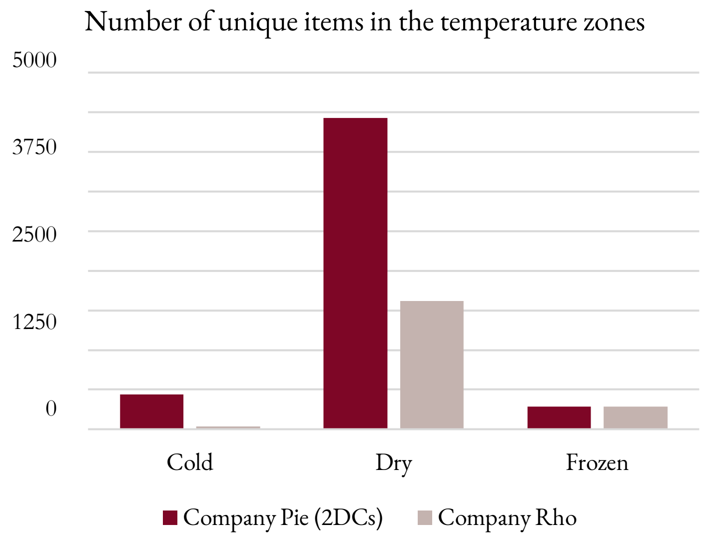


Figure 4.11 Number of unique items in the temperature zones for Company Pie and Company Rho. Based on data from November 2022 from all three current DCs.

4.2 Current Distribution Centre Configuration

This subchapter aims to describe the current warehouse configuration at Company Pie and Company Rho, focusing on differences and similarities. The main distribution centre, PDC, will be used to describe Company Pie's configuration of operations. This DC is considered representative of the configuration at other Company Pie warehouses, based on information provided by Company Pie.

4.2.1 Distribution Centre Operations

This subchapter outlines the receiving, put-away and storage, picking, packing and shipping operations in the PDC and RDC.

Receiving

At PDC, operations begin with receiving of goods. Predominantly, pallets are used as the handling unit, with most SKUs arriving on standardized EU pallets. Goods are typically dispatched from factories to PDC, with an average of 80-100 trucks arriving inbound daily. Additionally, occasional container arrivals require special handling for unloading, which is currently outsourced at PDC, but the plan for the NDC is to handle container unloading internally.

Upon arrival, truck drivers place goods in a staging area with lanes, where one warehouse worker directs the flow, performs quality checks, sorts, and registers the deliveries into the WMS. When placing the pallets into receiving lanes, the pallets are placed with their long side parallel to the aisle. A visualisation of long side placement can be seen in Appendix IV. Due to varying fragility, goods are generally not stacked, and there must be a space of 10-15 cm between lines and pallets to enable quality checks. Pallets need to be of the correct height to fit storage space, which sometimes requires splitting in the staging area. Frozen SKUs can remain in the receiving area for 10 minutes, cold goods for 10-15 minutes, while dry goods have no time constraints as the entire PDC is controlled to ambient conditions. Receiving goods is deemed the most demanding part of operations at PDC.

Receiving operations in both PDC and RDC share commonalities, yet notable differences exist between them. In Company Rho, an increased number of suppliers in Asia leads to more frequent container deliveries compared to PDC. While the current frequency stands at approximately one container per week at PDC, this is expected to rise in the NDC. Efforts to handle container unloading and palletisation internally aim to minimise costs, but this poses challenges due to additional handling and time constraints. Furthermore, mixed pallets that need splitting before storage arrive more frequently in RDC than in PDC. Breaking up mixed pallets is therefore a larger part of the receiving process at the RDC.

Put Away and Storage

After receiving, pallets are picked up from the receiving area and placed into storage locations determined by the WMS. All pallets are stored according to a long-side policy to enable more ergonomic picking, as the PDC operates as a manual warehouse. Pallets are registered into storage by scanning a barcode at the storage location. Since both PDC and RDC handle perishable products, all storage must adhere to FIFO principle. Storage allocation is based on temperature zone, weight, and product movement. Both PDC and RDC implement a family grouping storage allocation method, with zones designated for different temperature requirements and class-based storage based on weight and fragility. The put-away process is coordinated to facilitate the picking process, with heavy items placed in convenient locations since these are picked first.

In Figure 4.12 below, the stock levels at all Company Pie and Company Rho warehouses are displayed. The zone distribution within the DCs can be seen on an aggravated level, showcasing that the predominant part of the SKUs is stored in dry temperature. A smaller portion is stored in cold and frozen areas. Furthermore, the number of pallets is greater than the number of SKUs in the dry zone, this indicated that some SKUs have more than one pallet in stock. In the frozen zone the reverse is true.

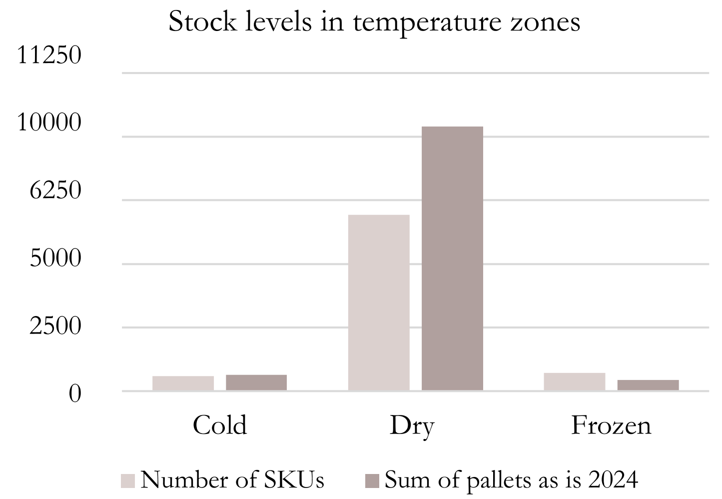


Figure 4.12 The distribution of SKUs and number of pallets in each of the temperature zones, cold, dry, and frozen. Based on data from November 2022 from all three current DCs.

Order Picking

The picking process begins with assigning a pick order to an employee, determined by the WMS based on completion deadlines. The sales orders are consolidated into order lines at the PDC by combining sales orders shipped on the same date to the same, or nearby, address. Sales orders typically contain a mix of fast- and slow-moving items, sometimes divided into different work lines. The PDC has a lot of customer specific SKUs, and almost every order contains a unique SKU that is for the customer. This indicates that almost every order contains at least one slow mover.

In the PDC, the frozen storage is a separate pick zone, orders here are picked in parallel with the rest of the DC and staged for shipping in the frozen area as well. The picking method employed over the DC is "pick by individual order" due to weight restrictions of the handling equipment and to streamline the staging process before shipping. The picking process is carried out by an operator through retrieving an empty pallet, and then travelling to all pick locations to load SKUs onto the pallet.

Pickers adhere to a specific policy, where heavy products are picked first, followed by medium, and light products last. Additionally, picking starts with start with dry SKUs, then cold. The typical finished pallet can be seen in Figure 4.13.

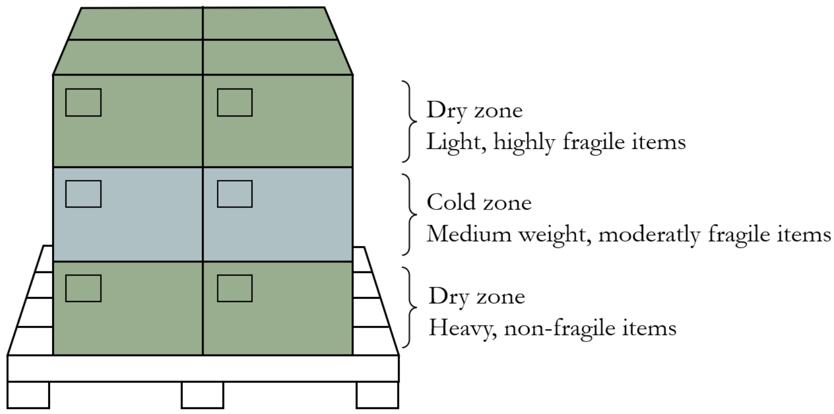


Figure 4.13 A visualisation of the reasoning behind how orders are placed on pallets in PDC.

Another part of the pick operation, that is not directly value adding is replenishment. Since the vertical storage locations are used as a buffer zone, operators need to use a reach truck to replenish the fast pick area. The fast pick area is the lower two levels of a rack. When doing this a plastic wrapping that is around the pallets is removed to allow for smooth picking.

Packing and Shipping

Prior to shipping, pallets are transferred to a staging area comprised of designated lanes. Each order is assigned to a single lane. Before entering the staging area, pallets are packaged and labelled with a shipping barcode. The staging area is maintained at a refrigerated temperature of 2-4 degrees Celsius. Upon arrival, truck drivers receive a picklist and transport pallets to their vehicles accordingly.

4.2.2 Distribution Centre Design and Resources

When it comes to the physical layout of PDC and RDC, the most important take away from collection of data is that the challenges at the PDC are partly attributed to capacity constraints, as the facility is undersized for the current stock volumes. Furthermore, the facilities need renovation. In Figure 4.14 below the utilisation of each temperature zone can be seen. The company goal is around 80 percent utilisation, which is far superseded in almost all areas, sometimes even exceeding 100 percent. At times the utilisation also drops to around 50 percent in some areas.

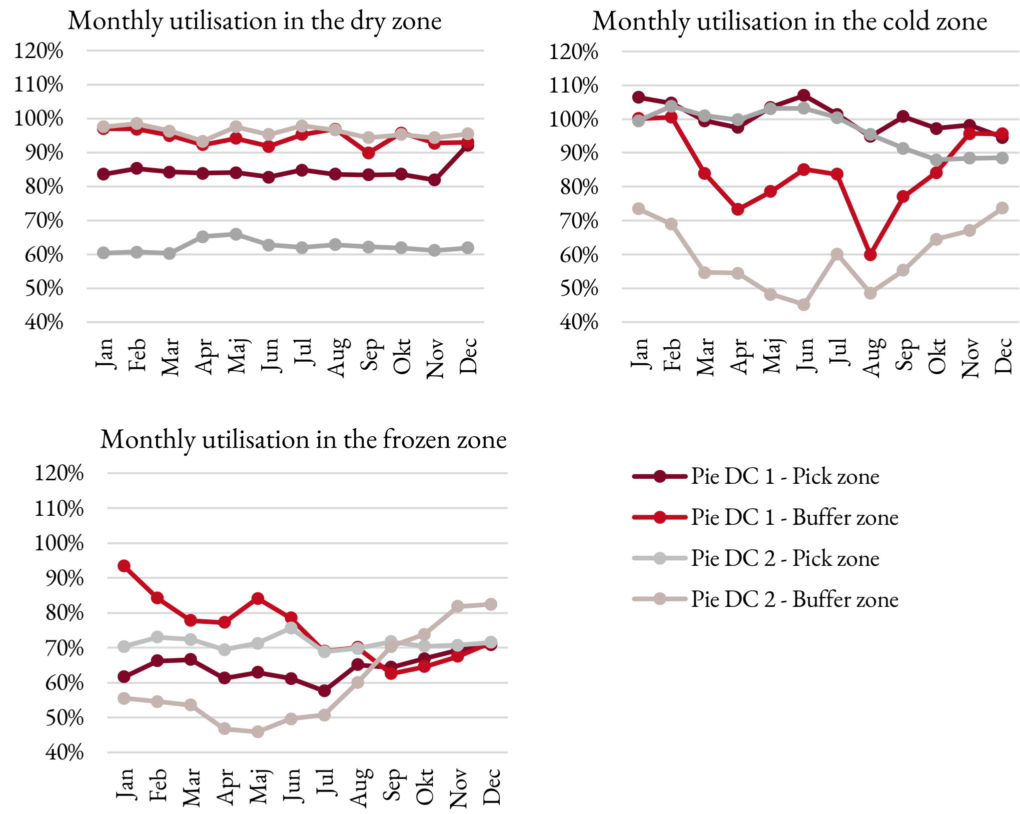


Figure 4.14 Monthly utilisation rate in the different temperature zones at Company Pie's current two DCs during 2022. Pick zones and buffer zones are presented separately.

Storage and Handling Equipment

The current storage equipment at PDC and RDC primarily consists of single-deep racks arranged in parallel aisles, with smaller shelves for carton or piece picks, alongside lanes for fast-moving heavy SKUs. In PDC, SKUs are stored in five high single-deep racks, except for fast-moving stackable goods, which can be stored in lanes close to outbound and stacked up to three high. In the racks, the lower levels are preferred for fast moving and heavy SKUs. The higher levels are used as a buffer zone.

Since PDC is a manual DC, the handling equipment used is counterbalance trucks to perform picking and put away, reach trucks to replenish, and hand pallet trucks to move goods around in the inbound and outbound area of the warehouse.

The storage equipment used in RDC is similar to PDC, single deep racks for pallets and shelves for cartons and less than a carton. However, RDC experiences a higher frequency of handling units being cartons or smaller, necessitating a larger shelving area. Furthermore, RDC has a mobile rack in one of the dry zones. This is not expressed as something that is desirable and is an inherited investment. In terms of handling equipment, the equipment used is the same, or similar to PDC and there are not any SKUs that need to be handled with different equipment than in the PDC.

Warehouse Management System

The WMS used at Company Pie is Microsoft Dynamics 365. No information about the WMS used at Company Rho is provided, but it is planned for both companies to use Microsoft Dynamics 365 in NDC. The system is deemed adequate to handle most warehouse operations, with good opportunities to install new modules if needed.

The current DCs, PDC and RDC are manual warehouses and have no automated handling equipment.

Summary of Findings Regarding Warehouse Configuration

To summarise the empirical findings regarding configuration at PDC and RDC the most important findings are highlighted in Table 4.3 below.

Table 4.3 Summary of the configurational findings in PDC and RDC.

Warehouse Operations		
Configuration	**PDC**	**RDC**
Receiving	Full pallets, mixed pallets, and containers	Full pallets, mixed pallets, and containers
Put away & storage	Correlated storage based on temperature and class based on weight and fragility	Correlated storage based on temperature and class based on weight and fragility
Picking	Single order picking	Single order picking and cluster picking (for smaller items)
Warehouse Design and Resources		
Configuration	**PDC**	**RDC**
Storage equipment	Single deep racks and shelves for smaller SKUs.	Single deep racks, shelves for smaller SKUs, and mobile racks.
Handling equipment	Counterbalance trucks and reach trucks	Counterbalance trucks and reach trucks
WMS	Microsoft Dynamics 365	No information
Automation	None	None

4.3 Preconditions of the New Distribution Centre

The purpose of PDC and RDC is to consolidate products for customer orders and ensure that deliveries are ready on time. The reasoning behind consolidating the RDC and RDC into a new DC is achieving economies of scale, consolidating deliveries to customers, and improved efficiency and flexibility. Thus, the configurational goals of the NDC are threefold, picking efficiency, ergonomic workplace environment, and storage capacity.

One of the largest differences between operations in RDC and PDC is that warehousing has never been a core business at Company Rho. Therefore, operations lack in efficiency and one of the objectives of consolidating the companies in the NDC is to improve efficiency for Company Rho while not compromising the efficiency of Company Pie. Another objective is to allow for higher flexibility in introducing new SKUs, particularly for Company Rho.

4.3.1 Operational Challenges for the New Distribution Centre

When it comes to operations, the warehouse workers seem to find them straight forward, the only process that is brought to light as something more challenging is receiving. This is due to this process being more complex than the other processes, making it harder to learn. The fact that pallets arrive with mixed product, needing splitting, is also a factor that makes this process more time consuming. The lack of uniformity in unit handing is derived from the difficulty to negotiate standard packaging globally. Furthermore, having more deliveries consisting of containers, which require a separate process to empty, will add a further layer of complexity. Due to the time frame of this thesis work, these issues will not be further investigated in the analysis and artefact.

When it comes to put away and storage, the challenges derive from perishable products having different temperature requirements entailing that they cannot be placed anywhere in the warehouse. Furthermore, the weight and fragility of different SKUs also places a constraint on where they can be stored. A challenge to consider when using AGVs for put away is also uniformity in unit handling and removal of obstructions, such as plastic wrap, around pallets. The plastic wrap is used to keep items from falling of pallets and to maintain quality.

One of the challenges that was brought to light in the picking process was that almost every order contains a slow mover. This is because almost every customer orders at least one customer specific item. This can be for example packaging with the customers logo. Another challenge is the high ABC skew in popularity in the warehouse, meaning that few items stand for most of the activity of the DC.

4.3.2 Design and resources for the New Distribution Centre

Based on the configurational goals for the NDC there are multiple decisions to be made. There needs to be a decision made on handling standardization, whether pallets should be handled long side or short side, or if there should be a mix. There also needs to be a decision around utilisation, especially during the first years of implementation when the storage space is too large to satisfy the 80 percent utilisation rate desired by the corporate strategy.

Today, Company Pie's PDC is insufficient to accommodate its turnover, leading to excessively high utilisation rates. The objective for the NDC is to achieve a utilization target of approximately 80 percent across the entire facility. Additionally, a notable challenge arises from the predominantly manual operations in all current DCs. To address this, a decision has been made to integrate AGVs into the configuration. However, further exploration is required to determine the specific utilization of AGVs and their prerequisites within different operational areas.

The layout of the NDC can be viewed in Figure 4.15 below. The areas for dry, cold, and frozen storage are highlighted, as well as an office and truck room area. Inbound and outbound docks are visualised with arrows. The dotted line represents a mezzanine floor where Company Rho production is going to be placed. The area assigned for each temperature zone is static. However, location of doors between temperature zones in the NDC can still be decided.

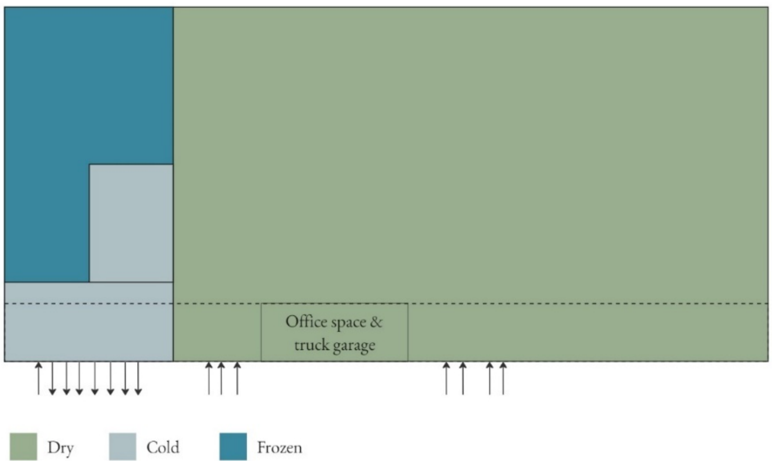


Figure 4.15 Current layout of the NDC with highlights of the temperature zones and inbound and outbound flows.

The handling equipment used in the NDC is going to be the same as in PDC, except for AGVs. When looking at the technical specification sheet of the AGVs it can be concluded that all aisles in NDC need to have a minimum width of three metres. The height of the NDC also allows for racks that are seven stories high.

5 ANALYSIS

In this chapter the situation at Company Pie's NDC is analysed by identifying the main contextual factors and their impact on the warehouse configuration. The analysis determines which configurational elements are most suitable for the specific context. The numbers presented are anonymised to not reveal any confidential information about Company Pie. In Figure 5.1 below, a part of the framework for data collection and analysis is displayed. This illustrates how the analysis aims to identify main contextual factors, identify what configurational elements are affected and finally investigate what configurational elements are suitable for the company context.

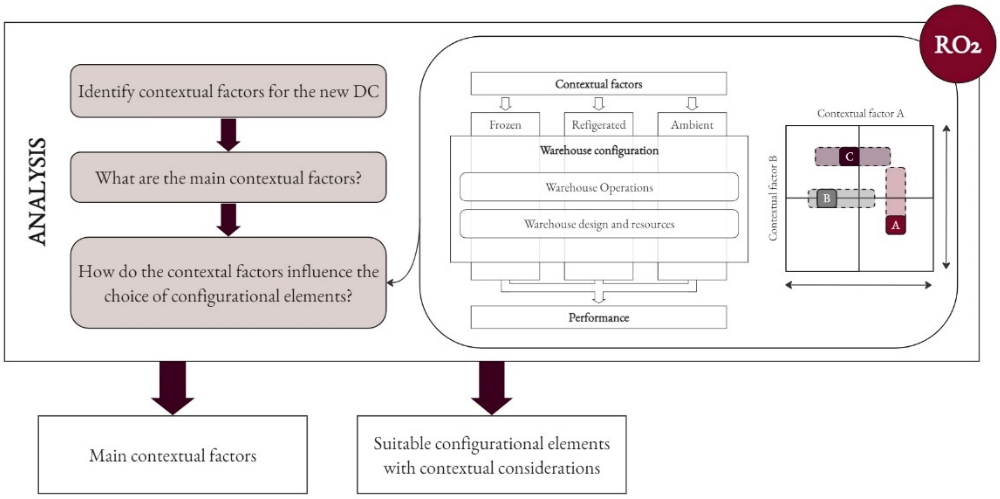


Figure 5.1 Outline of the analysis from the framework for data collection and analysis.

5.1 Contextual Considerations

The empirical findings show that there is a high level of complexity which can be ascribed to the contextual factors. The complexity manifests through the order, SKU, and goods differentiation, and lack of package standardisation resulting in a task complexity (Kembro & Norrman, 2021). Within a dynamic environment, contextual factors stand out as factors that cannot generally be controlled, only adapted to, or avoided (Eriksson, et al., 2019). To narrow down which configurational elements are especially important for Company Pie, the relevant contextual factors and their implications are analysed. The contextual factors that are deemed less important in this case are factors that can be changed or that are overruled by the impact of other contextual factors, or because they are not as important to the thesis scope and focus. They are also identified based on their importance for achieving configurational goals.

To decide which factors to focus on, the contextual factors in this thesis are categorised into focus and miscellaneous, which can be seen in Table 5.1. The factors which are in focus are the ones deemed important for the configuration of the new DC while the miscellaneous are deemed less important for this thesis according to the logic presented in the previous paragraph.

Table 5.1 Identified contextual factors based on empirical findings.

Contextual factor	Description	Focus or Miscellaneous
National legislation	National standards and regulations.	Miscellaneous
Customer characteristics	The number and type of customers, as well as their preferences.	Miscellaneous
Demand profile	Variance in order profiles and determines how often SKUs are picked and what volume.	Focus
Order characteristics	The number of orders, work-lines per order, and number of each SKU per order.	Focus
Product characteristics	The attributes of the SKUs, such as their size, weight, fragility, temperature etc.	Focus
Corporate strategy	For example, market expansion, mergers, and acquisitions.	Miscellaneous
Warehouse role	The role that the warehouse has in the internal network.	Miscellaneous
Assortment	The mix of items offered to customers.	Focus

National legislation is deemed miscellaneous for this thesis since the legislation and other industry guidelines are deeply rooted in the organisation and current operations and offer little room for change. Additionally, the authors argue that the regulatory requirements often are reflected in for example the product characteristics which is a focus factor. Due to confidentiality reasons, as well as limited data provided by Company Pie, customer characteristics and corporate strategy are deemed miscellaneous. Finally, the warehouse role, is deemed miscellaneous due to it being overruled by other factors allowing for more quantitative data analysis.

Demand profile is the first contextual factor that is deemed to have a large impact on the NDC. Since the perishable products have variations in seasonality related to various holidays and celebrations, the inventory levels can have large variations over the year which can be seen in Figure 4.14. This can partly be ascribed to large volumes of incoming goods with low frequency and is therefore not necessarily an indication of the demand. However, the overall order distribution in the DC over the year is relatively constant, with a slight increase during the second half of the year as seen in Figure 4.2, which gives a better indication of the demand. Growth and the increased volume due to consolidation is also important to take into consideration since the product assortment range is expanded by merging Company Rho.

The second contextual factor that is in focus is order characteristic. The order characteristic when merging Company Pie and Company Rho is different due to more orders containing multiple picks. The number of orders, work lines per order and number of each SKU per order differs when combing Company Pie and Rho in the NDC rather than having them separated into PDC and RDC. This means that the storage and picking operations need to be configured to adapt to this context.

Product characteristic is the third contextual factor in focus for Company Pie. The products stored in the warehouse are of perishable nature, and therefore there is a need for storage conditions adapted to the temperature requirements specified for the different categories of perishable goods. To be more specific, refrigerated product needs to be stored in a refrigerated zone and frozen product needs to be stored in a freezer. Furthermore, due to expiration dates the principle for storage in the DC must be FIFO. There is also a large variety of SKUs. From the data collected the variety of weight and fragility is important and can be divide into three classes based on stackability. This entails that all products cannot be stacked upon each other, and the storage equipment needs be chosen with this aspect in consideration. Furthermore, the sheer number of SKUs with large variations in product characteristics entails that standardization is limited.

Lastly, the assortment is deemed to be a contextual factor in focus. When dealing with perishable goods in the food industry the flexibility of being able to introduce, new products and provide a diverse assortment for customers is also important. Consequently, the warehouse operations must be agile enough to adjust to these changes in SKU demand without affecting the overall efficiency.

5.2 Distribution Centre Configuration

The focus contextual factors need to be considered when configuring the new DC. In the subchapter below, the different contextual factors are analysed in terms of how they affect the new configuration. The analysis, and therefore the artefact of the physical layout has three focus areas, determining appropriate storage methods, designing an efficient picking operation and placement of storage equipment.

5.2.1 Distribution Centre Operations

This section focuses on how to configure the storage allocation and picking operation of the NDC. The receiving operation and shipping operation have not been a focus of the thesis and will not be a part of the analysis, nor the final artefact. Each of the subchapters start with selecting a configuration at a general DC level and continues to determine suitable configurations on a more granular level.

Selecting Storage Allocation Method

The primary contextual factor imposing a constraint on configuring any Company Pie DC is the temperature requirement for storing perishable goods (Yurtseven, et al., 2022). By integrating insights from literature and empirical findings, Figure 5.2 illustrates how the main contextual factors affect which storage allocation methods yield the largest benefits. The contextual factors outlined in the figure adhere to the DC as a whole, encompassing the similarity among the SKUs stored in terms of temperature requirements, as well as the similarities in orders, such as the frequency with which SKUs are ordered together. The placement each of the storage allocation methods in Figure 5.2 is based on logical assumptions from Table 2.2, from the frame of reference chapter, based on Frazelle (2016) and Thomas & Meller (2014).

Family grouping is considered suitable for the DC as a whole due to the three shared temperature requirements among SKUs. Consequently, the entire DC should be segmented into family grouping zones based on the temperatures dry, cold, and frozen. When determining the appropriate storage allocation method within these temperature zones, reference to Figure 5.2 proves valuable once more. Empirical evidence, specifically the ABC analysis in Figure 4.9, reveals significant variations in item pick frequency within each temperature zone, indicating variations in popularity for different items. This implies that the storage allocation method to use within the temperature zones is class-based storage based on picking frequency (Thomas & Meller, 2014).

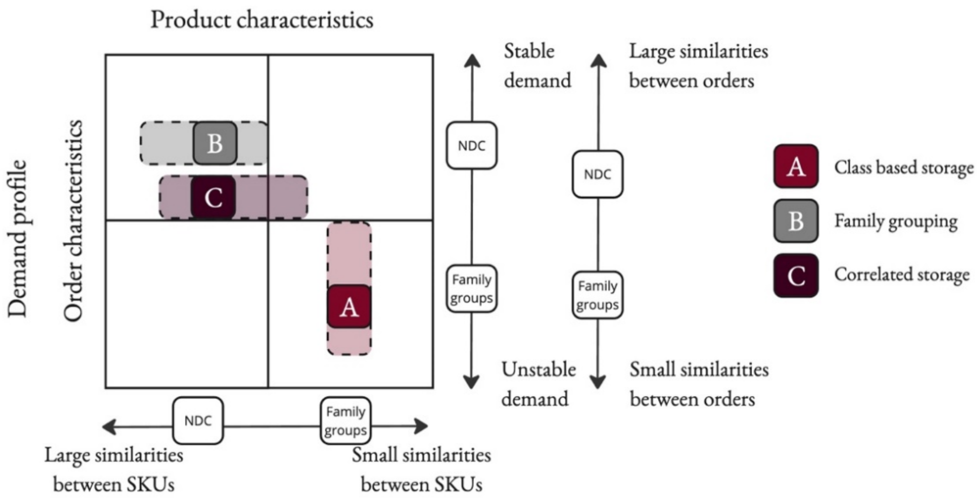


Figure 5.2 Which storage allocation method to use based on order and product characteristics.

Additionally, a decision is made regarding the storage strategy within the class-based storage. Figure 5.3 illustrates the focus contextual factors within Company Pie that influence the selection of a storage strategy and guides the decision-making process. Considering that random storage offers greater space efficiency, it is preferable in DCs with high throughput and in buffer zones, suggesting its implementation across the entire DC (Bartholdi III & Hackman, 2019). However, certain SKUs within the family group dry class A - zone (Dry-A Zone) possess unique characteristics, such as frequent picking and larger number of pallets in stock. These SKUs, listed in Table 4.2, can be allocated to a dedicated storage area within the A-Dry Zone, organized into lanes based on an optimal lane depth calculation from Bartholdi III & Hackman (2019).

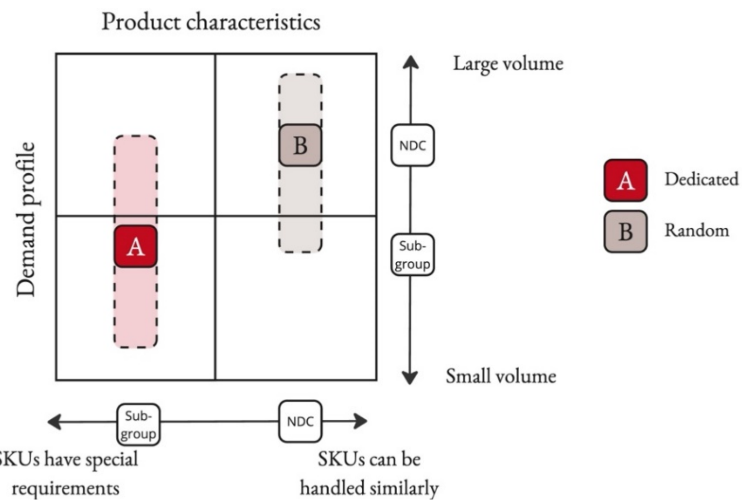


Figure 5.3 Which storage strategy to use based on demand profile and product characteristics.

In Table 5.2 a summary of the analysis related to storage allocation can be seen together with the take aways from the analysis. On an entire DC level, the storage allocation method decision is that product should be stored according to a family grouping method based on temperature requirement. Within these family groups products will be stored according to class-based storage based on pick frequency. Finally, within the classes in the class-based storage product will be stored randomly except for the items in Table 4.2 which will have dedicated storage. This will serve as input for operational configurations when designing the artefact.

Table 5.2 Summary of analysis selection of storage allocation method.

Level	Configuration	Decision	Take away from analysis
Entire DC	Storage allocation method	Family grouping	Physical separation of storage areas in DC based on storage temperature. Frozen, dry, and ambient storage zones.
Within temperature zones based on family grouping	Storage allocation method	Class-based storage	Within the temperature zones, class-based ABC based on pick frequency should be used to minimise travel.
Within Classes in class-based storage	Storage strategy	Mixed random and dedicated storage	Within the ABC zones, random storage everywhere except for SKUs with high throughput in the Dry-A zone.

Determining Order Picking Method

As presented in Chapter 2.1.1, external and corporate contextual factors influence internal warehouse decisions. Among these decisions, the selection of a picking method holds importance, impacting various other warehouse operations. In Chapter 2.1.2, picking methods are outlined, and by reviewing the literature the decision regarding their adoption is influenced by both order and product characteristics. Specifically, the quantity of SKUs in the DC and the number of picks per order. Figure 5.4 below provides an analysis of which picking method to choose based on the contextual factors. The picking method is determined depending on the number of picks per order and the size of the product assortment.

Based on the collected data, the NDC will have, as presented in Chapter 4.1.2, 8232 unique items which constitute a considerable number of SKUs. Additionally, the number of picks per order is deemed to be moderate based on the finding that a majority of the orders have 9 or less picks which is shown in Figure 4.3.

Consequently, according to literature, the most optimal picking method for the DC as a whole is zone picking (Richards, 2018; Petersen & Aase, 2004).

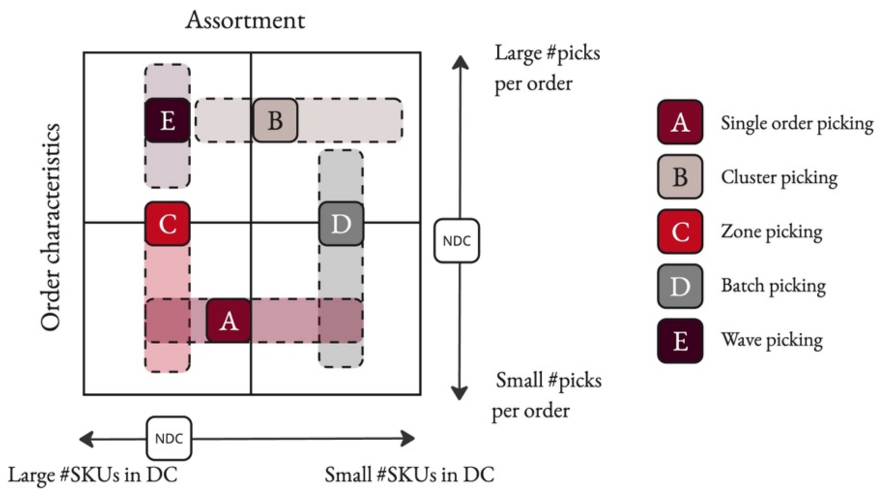


Figure 5.4 Which picking method to use based on product and order characteristic.

After having determined that the most suitable picking method for the DC as a whole is zone picking, the next step to look at is the configuration of the different picking zones, and whether they should be separate or integrated, which is guided by Figure 5.5. From the findings presented in Chapter 4.1.1, specifically the section about order characteristics, it is shown in Figure 4.6 and Figure 4.7 that there is a large difference between orders, both between the different temperature zones, but also within the zones. The findings also indicate that most orders contain at least one slow-moving item. Additionally, in Chapter 4.1.2 Figure 4.10 show that there is a significant number of pallets in the DC, indicating large volumes. Based on this it is deemed appropriate to have separated picking zones in the DC, which is illustrated in Figure 5.5.

Continuing, the picking zones are determined. Knowing there is a need to separate the frozen products from the cold and dry products, it is logical to separate them as different picking zones. This is further supported by the significant differences in regards to orders, displayed in Figure 4.5, Figure 4.6 and Figure 4.7. Furthermore, it is deemed appropriate to separate slow moving items in the dry zone given the NDC's size, and the considerable distances to cover during order picking. However, if distances between areas are smaller and orders exhibit similarity, integrated picking areas are more suitable which is the case for the cold and dry zone. This is supported by the findings illustrated in Figure 4.4 and Figure 4.13. To conclude, the three following picking zones are suggested: Zone 1 comprising the entire frozen area, Zone 2 comprising the entire cold area as well as the area in the dry storage area with class A and class B items, and Zone 3 comprising the dry area with class C items. When it comes to sorting and consolidating the orders picked in Zone 2 and 3 parallel functioning is suggested at the conclusion of a picking route in Zone 2. This reasoning is based in empirical data and logical decisions regarding reduction of time and travel distances in the DC, to support this decision travel distances and time will be evaluated in the artefact.

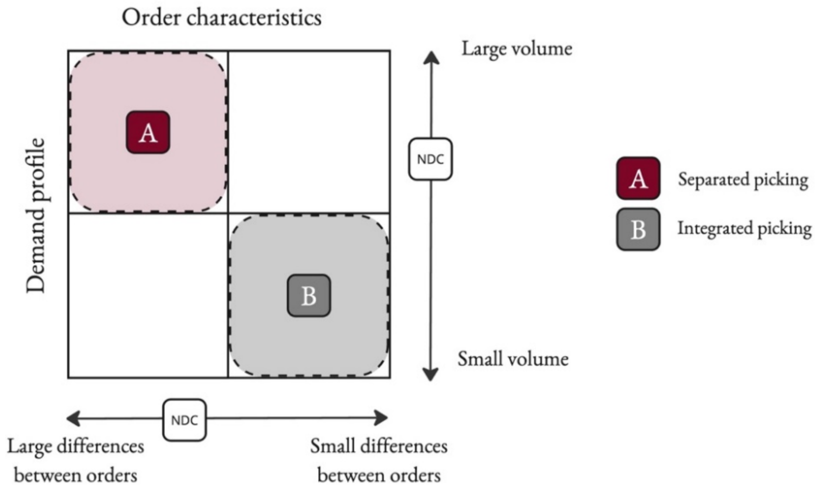


Figure 5.5 Weather or not picking operations should be separated or integrated over zones based on volume and order characteristics.

Given the necessity for separate picking zones, it becomes crucial to determine the most appropriate picking policy for each of the three pick zones (Zone 1, 2 and 3 presented above). The analysis between which policy to use in which context can be seen in Figure 5.6. In Zone 1, the freezer area, there exists a smaller number of generally medium-sized SKUs with predominantly small orders, making batching a favourable choice. Conversely, Zone 2 exhibits a wide variety of SKU sizes and larger orders, suggesting single order picking as the optimal method. However, the decision between single-order and batch picking depends on the composition of SKUs; if there are predominantly large SKUs, single-order picking is preferable, whereas if smaller SKUs dominate, batch picking is more suitable (de Koster, et al., 2007). Insufficient data regarding SKU size in pick zone 3 currently exists in Company Pie and Rho's information systems to make a definitive determination in this regard.

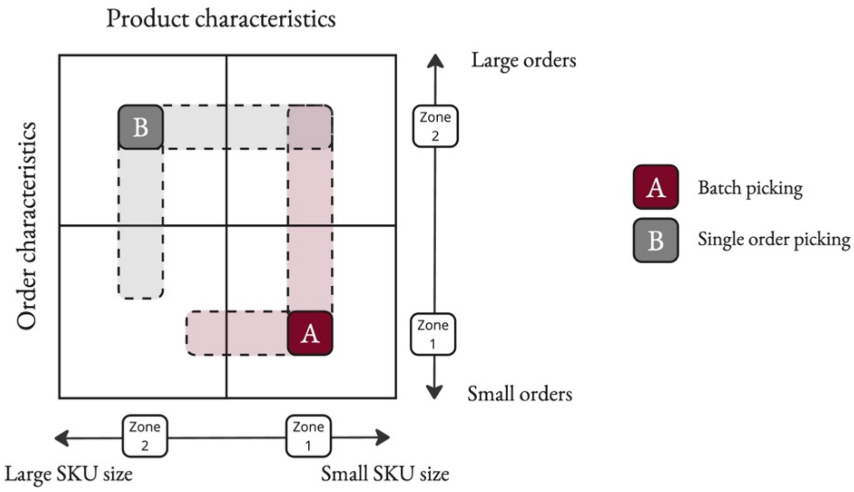


Figure 5.6 Which picking method should be based on product and order characteristic.

The final decision revolves around whether orders should be picked serially or in parallel within each picking zone. In zones with a smaller number of picks, meaning the individual pick zones, serial picking is recommended to streamline operations and reduce complexity, such as the need for handovers and additional sorting (Bartholdi III & Hackman, 2019). Conversely, for higher activity areas, such as the picking zones 2 and 3, parallel picking becomes necessary to meet demand efficiently and reduce travel time in zone 2 (Bartholdi III & Hackman, 2019). Therefore, a designated handover area should be established where workers from zone 2 can retrieve SKUs picked in zone 3 at the conclusion of their picking routes.

In Table 5.3 below, a summary of the analysis with regards to picking operations can be viewed. The table is divided into the three different decision levels within the DC. On an entire DC level, the pick method is zone picking divided into three separate picking zones. Pick zone 1 is the frozen storage, pick zone 2 is the cold storage and the area where class A and B items are stored in dry, and finally zone 3 is the area where class C items are stored in dry. In zone 1 the decision is that the pick method used is batch picking. In zone 2 single order picking is used and in zone 3 more data is needed to make a more definite decision.

Table 5.3 Summary of the analysis of picking operations based on contextual factors.

Level	Configuration	Decision	Analysis take-away		
			Zone 1	Zone 2	Zone 3
Entire DC	Pick method	Zone picking	Frozen	Cold + Dry A & B	Dry C
Between pick zones	Pick strategy	Mixed with parallel picking between zone 2 and 3	Separate	Separate with handover from zone 3	Separate with handover to zone 2.
Within pick zones	Pick method	Mixed batch and single order	Batch	Single order	Inconclusive
	Pick strategy	Serial	Serial	Serial	Serial

5.2.2 Distribution Centre Design and Resources

This subchapter analyses which configurational elements in design and resources the NDC should adapt based on the contextual factors. First, the configuration of the physical layout will be analysed, then the storage and handling equipment, and finally the warehouse management system and automation.

Physical Layout

The physical layout of the new DC can be divided into decisions regarding flow configuration, utilisation of space, and aisle configuration as presented in the frame of reference section of this thesis. One of the main reasons behind the decision of moving to a new DC is that Company Pie has outgrown the old facilities and needs more space in terms of storage locations. In the new DC, the location of inbound and outbound docks is already determined. Furthermore, the flow when picking an order in the NDC should be optimised. Since the NDC has product movement with a strong ABC skew, the appropriate flow configuration to use is u-flow (Bartholdi III & Hackman, 2019). This is created by placing racks perpendicular to the inbound and outbound operation. However, since the DC is large and narrow with high volume movements in the zone with frequent picks, mimicking a flow through flow between inbound and outbound is beneficial (Op. cit). This is done by placing racks parallel to the inbound and outbound operation in the area where product that is frequently picked is stored.

The decision around utilisation is a trade-off between available space and cost (Richards, 2018). Since the NDC is too large for the current need for space, a decision regarding how excess space is to be used needs to be made. Either all space can be used, with the trade-off of having low utilisation and not exploiting available vertical storage, which incurs costs for maintenance, or space can be rented to other companies. A key factor to decide around, according to empirical findings, is whether to use short side handling, see Appendix V. Short side handling is more space efficient than long side handling, but less desirable in terms of work environment and ergonomics (Pankok Jr. & Hoyleb, 2015). Short side handling is more space efficient than long side handling, but less desirable in terms of work environment and ergonomics. Therefore, also confirmed by the exploratory focus group, short side handling should not be used in the frequently picked zones. However, mixing both short side and long side creates waste in operations since pallets will have to be turned in the receiving area and in handovers between areas. Based on this analysis, and the focus groups, the decision is that long side handing should be used across the entire DC.

The last decision regarding physical layout revolves around the aisle configuration. With the volume characteristic of a high flow and much available space, having many aisles is favourable. This decreases the risk of congestion and makes it easier to move around in the warehouse. Cross aisles can be used to reduce travelling distance between picks and is suitable for this context since orders contain a moderate number of picks (Bartholdi III & Hackman, 2019; Thomas & Meller, 2014). Since the software available for this master thesis is limited, only excel was used to generate layouts, the number of aisles is based on qualitative reasoning and is a trade-off between available space and utilisation.

The take-away decisions from this analysis and the reason behind them can be viewed in Table 5.4 below. The decisions are made prioritising picking efficiency over space utilisation, with many aisles and cross aisles. Since the space in the NDC is sufficient, the pick efficiency is prioritised. This table will be used guide the layout development of the artefact in the subsequent chapter.

Table 5.4 Summary of which physical layout configurational elements should be used.

Configuration	Decisions about	Reason
Space utilisation	Rack storage	Increase vertical storage.
	Lane depth	Increased space utilisation.
Material flows	U-flow	To save time during picking and put away if products have strong skew in popularity.
	Flow-through	For a large volume throughput.
Aisle configuration	Many aisles	Less congestion.
	Cross aisles	Allow for travel between aisles.

Storage and Handling Equipment

The storage equipment that should be used in the NDC needs to enable FIFO principles. Therefore, single deep racks or multi-deep pallet flow racks are two equipment types that can be used in the NDC. The racks should be high enough to make use for the vertical space. However, there is a trade-off in cost between additional time taken to replenish from a higher location versus the cost of lower storage (Richards, 2018). Since the volume of SKUs is increased in the NDC, the need for multi-deep storage is increased. The optimal bin depth is calculated using Equation 1 from the theory chapter and the result can be seen in Table 5.5 below. Which SKUs should be placed in multi-deep lanes of pallet flow racks should, according to empirical findings, be decided based on stackability and volume. These multi-deep storage locations should be placed in a convenient location close to inbound and outbound since they represent a large volume flow.

Table 5.5 The optimal bin depth for the items with the highest volume and in class A in the dry zone. Based on data from November 2022 from all three current DCs.

Storage type	Temperature	Class	#pallets	Item name	Optimal bin depth
Floorstack	Dry	A	134	Product 01	6
Floorstack	Dry	A	95	Product 02	5
Single Pallet	Dry	A	119	Product 03	6
Floorstack	Dry	A	74	Product 04	4
Single Pallet	Dry	A	304	Product 05	4
Single Pallet	Dry	A	132	Product 05	9
Single Pallet	Dry	A	124	Product 06	6
Single Pallet	Dry	A	116	Product 07	5

As for the handling equipment used in the NDC, excluding for the predetermined automated elements, it was decided by Company Pie that it should be the same as in the PDC. However, the high reach trucks will have the ability to reach higher than in the PDC to allow for utilising the full height of the NDC. The aisle width of the NDC needs to be adapted to the equipment with the largest turning radius. The pallet wrapping machine should be placed in the outbound area to not create congestion in the storage zones. A summary of the decisions reached through this analysis can be viewed in Table 5.6 below.

Table 5.6 Summary of which equipment configuration that should be used in the NDC.

Configuration	Decisions about	Reason
Racks	Single-deep racks	FIFO.
	Pallet flow racks	FIFO and high throughput volumes.
Handling equipment	Same as in current configuration, but with reach trucks that can reach to the highest rack.	No new handing requirements.
	AGVs	Decided by the company.

Warehouse Management System

A challenge that was detected in the information system is that there is a lack of documentation on weight and height of SKUs. Adding this information can create smarter allocations of SKUs and aid in automating put away of SKUs. The weight can help pick a more convenient storage location within the different zones since heavy items are picked first and fragile items last. Height is information that is required for put away to be handled by AGVs.

Automation

In this context, the product characteristics are very dissimilar from an automation perspective. They have large differences in size, fragility, and weight. AGVs are planned to be used in the entire warehouse for replenishment during the night, which entails that all aisles need to be manoeuvrable by the AGVs.

6 ARTEFACT DEVELOPMENT

This chapter finalises the purpose of the master's thesis by presenting an artefact for the new DC configuration 2028 and 2034. The framework for data collection and analysis, which stems from the warehouse design framework presented in chapter 2.4 has been used as a guideline through the project. Defining system requirements was addressed in the first chapter, introduction, as well as when summarising the findings in chapter 4. Defining and Obtaining data were covered in chapter 4 and 5. Chapter 5 also determined operating procedures and methods to use and in this final chapter the last steps of the framework, generate layouts and evaluate which is presented in Figure 6.1, is covered and tied together in a final artefact.

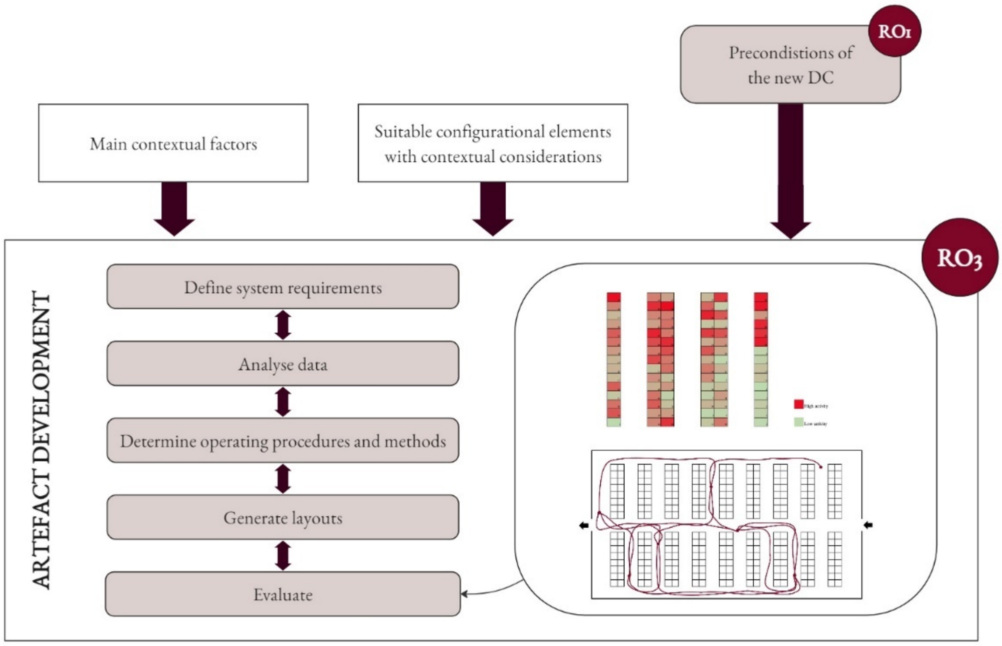


Figure 6.1 Outline of the artefact development from the framework for data collection and analysis.

6.1 New Distribution Centre Operations

Selecting storage method was the first step in the analysis and will be further concretised in this chapter. Products should be stored on EU pallets to standardize handing within the DC. Instead of the old storage policy, which entails that product are stored in zones according to weight, the new storage allocation method in the NDC should be Class-based due to the large difference in SKU popularity (Frazelle, 2002). Within the class-based zones the storage allocation strategy should be random, with the exceptions of goods that require special handing, in accordance with Bartholdi III & Hackman (2019).

In the analysis of the contextual factors, it was discovered that zone picking is the most suitable picking policy for the context of the NDC. A logical division of the assortment into different zones is frozen (Zone 1), cold and dry with frequent picks (Zone 2), and a zone with the slow-moving dry picks (Zone 3). This is reasonable due to the differences in temperature requirements and the product and order characteristic (Richards, 2018; Petersen & Aase, 2004). Another factor that supports this division is the size of the new DC with considerable distances to travel if all picks for an order are to be done by the same picker. This configuration was also confirmed during the Company Pie exploratory focus group.

On a more granular level, the picking policy of the zones is determined to be single-order in zone 2 and 3 due to the smaller number of SKUs placed in the individual zones and because of product characteristics in this context. The picking policy in Zone 1 should be batch-picking since the orders are smaller and product is also smaller.

The first step of the warehousing process, which is receiving is outside of the scope of this project in terms of recommendations, but there were numerous challenges found related to making this process more efficient. This part should still include sorting, inspection of the incoming goods as well as placing a barcode on the items to be able to scan them into the information system. Smooth unloading of arriving containers still must be determined and decisions on whether incoming pallets should be wrapped in plastic when put away since this can become a problem when using AGVs. Table 6.1 summarises which configuration to use in each of the decision levels and the reasoning behind the choices.

Table 6.1 A summary of which configuration to use in operations in the NDC.

Operation	Decision level	Configuration	Reason
Storage allocation method	DC	Family grouping	Storing SKUs together because of for example temperature requirements.
	Temperature zones	Class based	Suitable for large differences in SKU popularity
	Classes	Mixed	Random over DC to increase space utilisation. Dedicated for some SKUs with special handling requirements.
Picking method	DC	Zone	To be able to reduce travel distance and increase pick efficiency
Picking policy	Within zone	Mixed	Differences in product and order characteristic between zones. Batch picking in zone 1. Single order in rest.
Picking strategy	Within zone	Mixed	Serial in zone 1 and 3, parallel in zone 2 to reduce time.
	Between zone	Parallel	Parallel with handovers between zone 3 and 2.

6.2 New Distribution Centre Design and Resources

Designing the layout was highly dependent on which storage and handling equipment was going to be used. The aim of the configuration was to focus on the physical layout based on predetermined equipment decisions. To use new available height, all racks are to be build seven stories high. Most of the storage locations are single deep, in accordance with pallet volumes per SKU and FIFO. However, there is a small number of high moving SKUs for which five deep pallet flow racks are a better option. These are to be placed close to inbound operations and close to where a pick round starts since these items are heavy, non- fragile and picked in almost every order. The flow configuration of the warehouse is u-flow due to the placement of doors. However, for larger volumes flow through is a more desirable configuration. This is mimicked with horizontal racks in class-based storage A and B which handles large volumes.

The size of the area used for handovers between picking zone 2 and 3 was determined by calculating the workload quantity in zone 3 over a random Wednesday, since this is the busiest day of the week, during a peak month. Furthermore, it was assumed, based on the picking rate during a day, that about two thirds of the pallets picked in one day in zone 3 need to be stored simultaneously in the handover zone. This resulted in a need to store just over 250 pallets, and thus 100 pallets locations with three levels are dedicated to handover from zone 3 to zone 2. The height of the levels in the rack are somewhat lower than in the rest of the DC to ensure no special handling equipment is required in this pick area.

The aisle configuration is parallel aisles, with 80 percent utilisation, together with cross aisles to provide good accessibility and smooth flows. To conform with guidelines for work environment and ergonomics, pallets are placed according to a long-side handling policy. This decision was also discussed during the exploratory focus group, and it was confirmed that long side handling is not desirable in zones where manual workers conduct the picking operations. The parallel aisles are mostly vertical, in line with creating a u-flow configuration. In the area where SKUs are picked most frequently SKUs are placed horizontally to gain a flow through layout. A visualisation of the NDC layout from today to 2028 can be seen in

Figure 6.2 below which is rotated 90 degrees to make it easier for the reader to see the layout. In this layout, the utilisation in all zones in the warehouse is close to 95 percent, since Company Pie should expand its NDC during this year depending on the actual utilisation in practice.

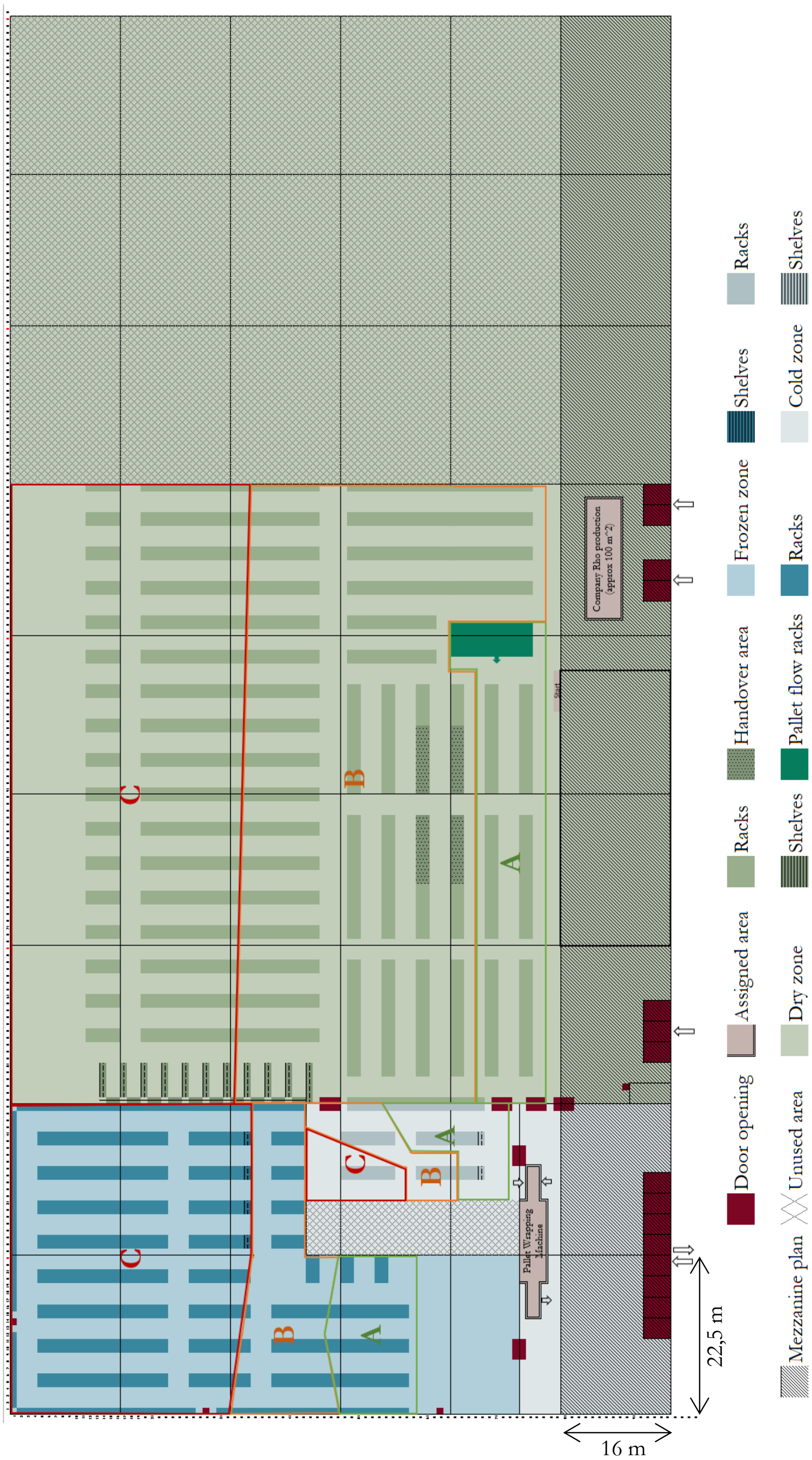


Figure 6.2 The physical layout of the NDC 2024 together with ABC zones.

Finaly the layout for year 2034 is presented in Figure 6.3. It is in many regards the same layout as for 2028, however, it is utilising all the available space in the DC. The class-based storage zones are almost the same as in the layout in 2028, the largest difference is the placement of class-based zones in the dry storage, since this is expanded. The placement of class-based zones is only illustrated in the dry storage in Figure 6.3 below since this is where the largest change occurs. The dry storage has a utilisation of about 80 percent and the cold and frozen storage has a utilisation of about 90 percent in this layout. It is possible to use more of the available space in the cold area, but the frozen storage needs to be built out if the prognosis is accurate in 2034.

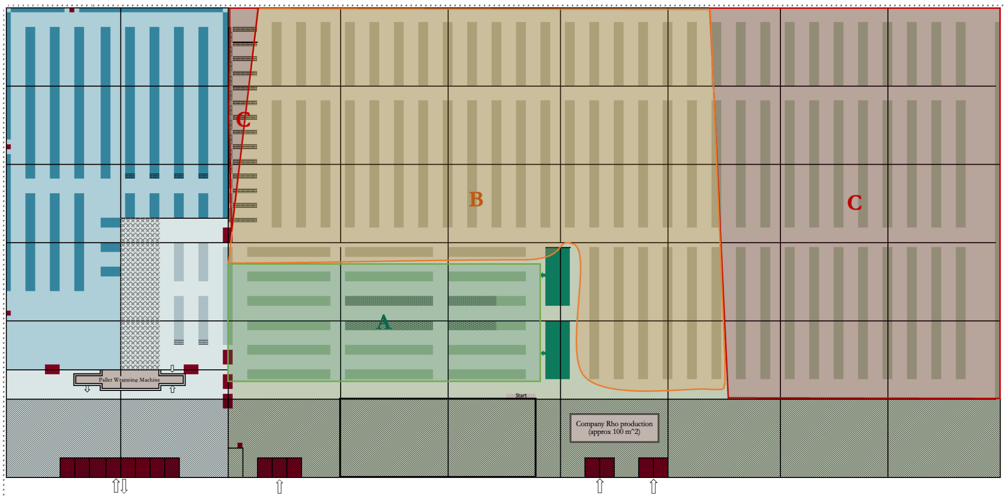


Figure 6.3 The physical layout of the NDC in 2034 together with ABC zones.

6.3 Evaluation of the Artefact

This chapter serves as an evaluation of the artefact and a discussion about its usefulness in practice in line with design science methodology (Dresch, et al., 2014). This is to make sure that the artefact holds value for Company Pie.

6.3.1 Artefact Flexibility

When assessing the artefacts utilisation, there are inherent risks associated with it exceeding 90 percent or falling below 70 percent utilisation. In a best-case scenario, utilisation in the DC is 80 percent, according to the exploratory and confirmatory focus group. If utilisation exceeds 90 percent, it can lead to operational bottlenecks, reduced flexibility, and increased strain on resources, potentially compromising efficiency and increasing the likelihood of errors and delays. On the other hand, if utilisation drops below 70 percent, it indicates underutilisation of resources, leading to inefficiencies and higher operational costs due to the suboptimal use of available capacity. In the artefact of 2034, the utilisation of the frozen area exceeds the worst-case scenario, which is why the predetermined frozen storage area should be reevaluated. This is outside the thesis scope.

Estimating growth based solely on November data also presents risks. November may not accurately represent the entire years operational patterns due to seasonal fluctuations, peak periods, or unique events occurring within that month. Such limited data can result in projections that fail to account for variations in demand and activity throughout the year, potentially leading to misguided strategies and planning.

Moreover, Company Pie has provided growth estimates on a SKU level with a ten-year horizon. While these estimates are valuable, they carry inherent uncertainties. The long-term nature of these projections means they are susceptible to various unpredictable factors, such as market changes, economic conditions, and shifts in consumer behaviour. Relying on these projections without considering the potential for deviation increases the risk of overestimating or underestimating future needs, which could result in either overcapacity or resource shortages.

6.3.2 Artefact Performance

This subchapter will evaluate the artefact performance by discussing pick efficiency, synchronization across different zones, material flows and congestion areas, handing standardization, and automation. This will be done by calculations, discussion about implications, and visualisations of material and resource flows in terms of a heatmap and spaghetti diagram.

To evaluate picking efficiency, it is essential to calculate the distances travelled during the picking process to quantify the time saved. While theoretical calculations provide an initial estimate, the method must be tested and refined in practice to ensure accuracy and effectiveness. An initial calculation of the saved travel distance during a pick route in pick zone 2, shows that on average 87.5 metres are saved per pick in pick zone 3 if these SKUs are placed in a retrieval area in pick zone 2. The time spent on traveling 87.5 metres is 40 seconds with the available handling equipment. Over an entire day, this entails that 2.5 hours are saved during the picking process in pick zone 2. However, synchronization across different zones poses a significant challenge, as it requires careful coordination to avoid delays and inefficiencies. Evaluating the workload balance in real-world conditions is crucial to identifying and addressing any imbalances that may arise.

A heatmap analysis, which can be seen in Figure 6.4, further supports the evaluation by highlighting the locations of frequently picked SKUs. By positioning these items adjacent to each other, the overall travel distance can be minimised, thereby saving time. Additionally, creating a dedicated picking zone for distant areas, such as Zone 3, helps to avoid unnecessary travel to far-away locations. This strategic placement ensures that frequently picked items are easily accessible, thereby enhancing the overall efficiency of the picking process.

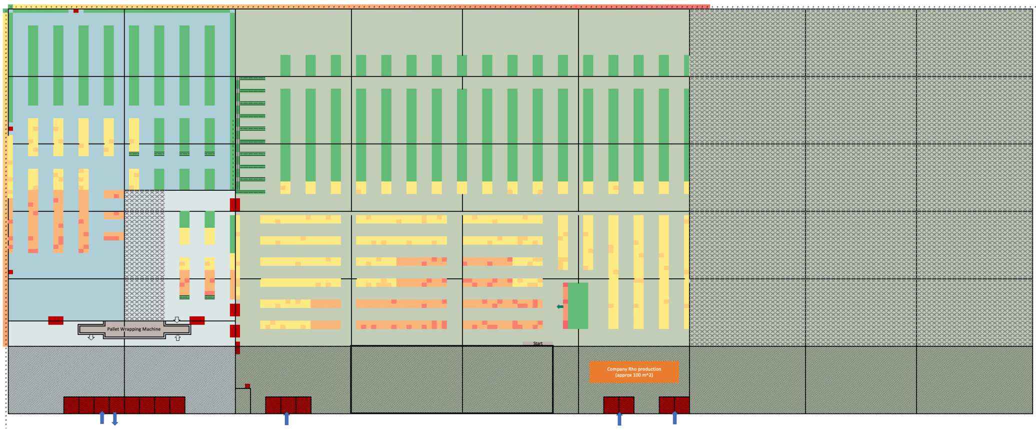


Figure 6.4 A heatmap of pick locations in the NDC, red colour indicated frequently visited locations, green indicates locations that are visited sporadically.

Storing products according to pick frequency can lead to congestion, as frequently picked SKUs are concentrated in the same area. Figure 6.5 illustrates the travel flows within the NDC, where high-traffic aisles are marked in red and low-traffic aisles in green this is inspired by spaghetti diagram (Quinn, 2023). To mitigate congestion, cross aisles have been implemented to facilitate movement between picking locations. However, the current analysis of SKU placement has been conducted at a general level. To further reduce congestion risks, a more detailed analysis at the granular SKU level is recommended, alongside practical testing of the proposed artifact. Additionally, it might be advantageous to allocate dedicated storage for more Class-A products in the dry zone, particularly if they frequently cause bottlenecks.

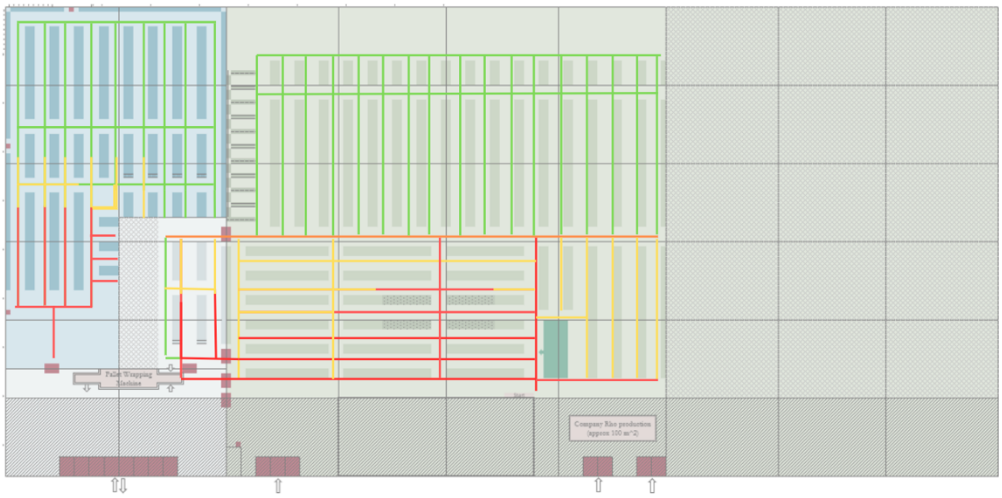


Figure 6.5 A visualisation of the travel flows in the NDC. Red indicated areas with high movement and green indicates areas with low movement. Congestion is a risk in red areas.

Additionally, using long side handing may contribute to less congestion since there are fewer pallet locations in an aisle than with short side handling, assuming the same aisle length. However, there are both pros and cons of long side handling. These are mainly space inefficiency and work environment, as previously discussed in the analysis. A combination of both short and long side handling can be considered a viable option. Unfortunately, a combination can led to inefficiencies, as the need to rotate pallets during put away and replenishment processes consumes valuable time and resources. While mixing handling approaches may seem versatile, it results in non-value adding activities and increased risk of ergonomic strain, ultimately hindering operational efficiency. Another downside to a combination, is a decreased flexibility when growth is accounted for in the artefact. Consequently, the artefact utilises long side handing across the entire DC.

Lastly, the interaction between humans and machines in the DC also raises questions about operational harmony. Using AGVs in the same spaces as human workers can slow down the movement of the vehicles (Zuin, et al., 2020). In the absence of standardised handling units, the transition toward a more automated DC necessitates a reassessment of the product assortment. Without standardisation, the efficiency of automation may be compromised, highlighting the importance of aligning the assortment with automation capabilities for seamless integration and enhanced operational efficiency.

7 CONCLUSION

This chapter summarises the results of this thesis project, tying together the framework for data collection and analysis seen in Figure 7.1. The conclusion represents the final step, fulfilling the purpose. The thesis purpose and objectives are revisited, suggestions for next steps are presented followed by the thesis' contribution. Finally, the limitations and future research will be presented.

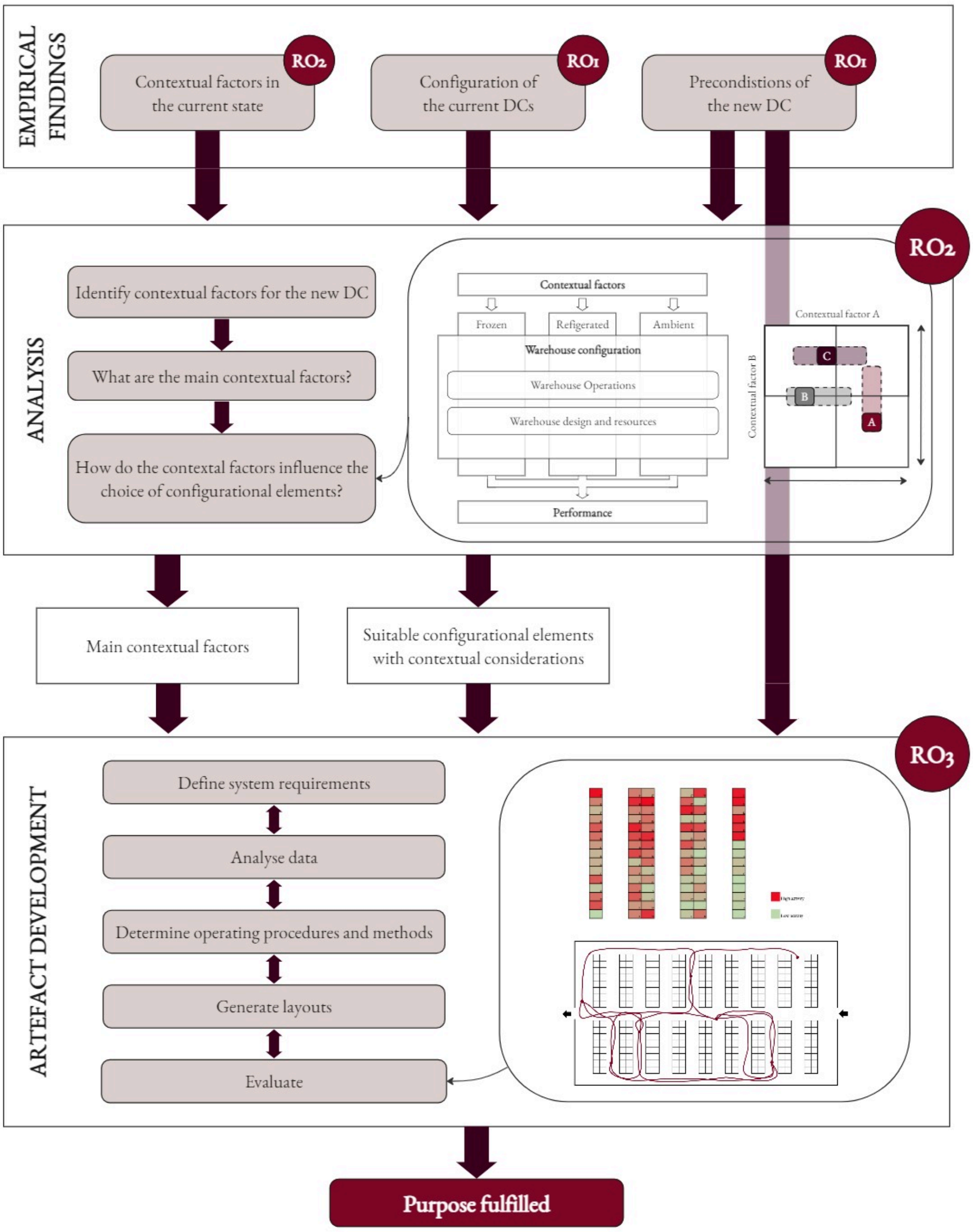


Figure 7.1 Framework for data collection and analysis.

7.1 Fulfilling the Purpose

The purpose of this thesis was to provide Company Pie with a new configuration, based on contextual factors and predetermined automated elements. Goals included improved picking efficiency by designing smooth flows within the DC. To fulfil the purpose, the current configurations at DCs at Company Pie and Rho were described, to understand the requirements of handing perishable goods, and to identify challenges and limitations in the current design. The contextual factors of the NDC were also identified to understand which configurational decisions should be made. From this identification it was possible to analyse which configurational elements the NDC should use, hopefully gaining performance advantages in line with contingency theory (Kembro & Norrman, 2021).

Finally, an artefact was developed which serves as a recommendation to Company Pie. The artefact included a layout for the NDC together with suitable pick strategy, pick policy, and storage allocation policy. Following the DS research method, the research was conducted by collecting qualitative data from interviews, observations, and quantitative data retrieved from the information systems.

7.2 Addressing the Objectives

The objectives of this thesis were to describe the current state at PDC, RDC and NDC, identifying contextual factors, and finally develop a warehouse configuration for the NDC. To conclude this thesis, each of the research objectives will be revisited.

RO1: Describing the Current Distribution Centre Configuration

The comprehensive description of the current states of the PDC, RDC, and NDC has yielded several insightful observations, particularly regarding the configurations with focus on operational practices of the PDC and RDC. Both the PDC and RDC exhibit similarities in their DC configurations and management practices, primarily driven by their shared focus on storing perishable goods and partially shared customer base.

The storage practices in both DCs are systematically organized according to temperature requirements (frozen, cold, and dry) and further categorised by fragility. This storage allocation method ensures that the subsequent order picking processes are streamlined and efficient, adhering to the specific handling needs of different products. Both the PDC and RDC utilise the pick method pick by individual order due to product characteristics.

In conclusion, the PDC handles large volumes and SKUs with well-functioning DC operations. Nonetheless, they are experiencing issues with space utilisation. The RDC handles smaller SKUs and volumes, however warehousing is not a focus for Company Rho and therefore RDC is not as resource efficient as PDC. The NDC is a large facility which satisfies both companies need for storage space and allows for extensive growth.

RO2: Identifying the Main Contextual Factors

Regarding Company Pie and Rho's context the main factors with significant influence on the configuration, and therefore the artefact, are order characteristics, product characteristics, demand profile and assortment. These factors play a critical role in shaping the DC configuration of the NDC.

The product characteristics have a large impact on the storage and picking process. The wide variation in product types, including differences in size, weight, fragility, and temperature requirements, made it challenging to standardise picking operations. Therefore, it was concluded that these product characteristics imply a configuration that involves separation when designing the storage and picking operations. A finding that further supported this was the growth in stock volume in terms of the NDC housing a larger volume of pallets than the PDC and RDC.

In addition to product characteristics, the integration of Company Pie and Rho within the NDC will bring changes to order characteristics. The nature of orders became more complex, with a moderate number of picks per order typically exceeding seven picks. This complexity was further compounded by the frequent inclusion of slow-moving items in approximately 65 percent of the orders. The presence of slow movers necessitates additional time and effort during the picking process, requiring planning to ensure these items do not hinder overall operational efficiency with extensive travel time due do the size of the new facility. Consequently, because of order characteristics, the artefact includes a pick method which separates the picking process into different zones over the DC.

In conclusion, the contextual factors of product and order characteristics, demand profile, and assortment influenced the development and adaptation of the storage and picking operation in the NDC. The identified main contextual factors together with their description and conclusion can be viewed in Table 7.1 below. The need to address the wide variation in product attributes and the complexities introduced by integrating Company Pie and Rho necessitated a flexible and dynamic approach. The adapted picking operation was designed reduce travel times accommodate the specific needs of different products, and manage the complexities of order characteristics, ultimately leading to a more robust operational framework in the NDC.

Table 7.1 Summary of the conclusions related to research objective 2.

Contextual factor	Description	Conclusion
Demand profile	Variance in order profiles and determines how often SKUs are picked and what volume.	Overall inventory level of the DC over the year is relatively constant.
Order characteristics	The number of orders, work-lines per order, and number of each SKU per order.	The number of orders differs when combing Company Pie and Rho in the NDC rather than having them separated into PDC and RDC.
Product characteristics	The attributes of the SKUs, such as their size, weight, fragility, temperature etc.	Perishable products with varying weight and fragility.
Assortment	The mix of items offered to customers.	Flexibility of being able to introduce new products and provide a diverse assortment for customers is important.

RO3: Developing a Distribution Centre Configuration

The findings from the description of the current configuration and the identification of contextual factors shaped the system requirements for the NDC configuration. These insights have provided a basis for the development of a suitable artefact tailored to the unique requirements of the NDC.

One of the key recommendations in the artefact is the adaption of a zone picking method with a class-based storage allocation method, organised according to the frequency of picks. This approach ensures that frequently picked items are easily accessible, thereby improving overall efficiency. The zone picking method allows for specialisation within different zones, facilitating a more streamlined and organised picking process. Moreover, the picking method also satisfies the order fulfilment time.

When it comes to the physical layout, the flow configuration in class A adapts a flow-through approach, accommodating the large volumes of goods passing through. In the artefact, this is achieved by placing horizontal racks in the storage area. The layout enables continuous movement and reduces bottlenecks, thereby enhancing the speed and efficiency of operations. Additionally, a u-flow configuration is recommended to address the variations in SKU popularity across the entire DC. This configuration supports efficient handling and storage of both high-demand and less popular items, balancing accessibility, and space utilisation.

In conclusion, the analysis of the current situation and contextual factors has led to a comprehensive set of system requirements for the NDC configuration. By implementing a zone picking method with class-based storage allocation and tailoring the picking operations and flow configurations to the specific needs of different zones, the new DC is set to achieve operational efficiency and productivity. These configurational adjustments are designed to enable efficient use of resource, accommodate to task complexity challenges, and provide an overall suitable and satisfactory DC configuration. A summary of which configuration to use on each decision level is presented in Table 7.2 below.

Table 7.2 Summary of the conclusions related to research objective 3.

Operation	Decision level	Configuration	Reason
Storage allocation method	DC	Family grouping	Storing SKUs together because of for example temperature requirements.
	Temperature zones	Class based	Suitable for large differences in SKU popularity
	Classes	Mixed	Random over DC to increase space utilisation. Dedicated for some SKUs with special handling requirements.
Picking method	DC	Zone	To be able to reduce travel distance and increase pick efficiency
Picking policy	Within zone	Mixed	Differences in product and order characteristic between zones. Batch picking in zone 1. Single order in rest.
Picking strategy	Within zone	Mixed	Serial in zone 1 and 3, parallel in zone 2 to reduce time.
	Between zone	Parallel	Parallel with handovers between zone 3 and 2.
Design	Material flow	Mixed	U-flow in the DC as a whole due to location of inbound and outbound as well as product having a strong ABC skew. Flow through in the area of class-based A storage 2034.

7.3 Next Steps

Throughout the development of the artefact, the configuration was continuously presented and discussed with stakeholders at Company Pie. This ongoing dialogue ensured that the artefact remained relevant, addressing real-world problems.

During focus group sessions, it was observed that company management tended to prioritise cost considerations, while warehouse managers favour designs that improves the work environment, especially focusing on ergonomics, and operational simplicity. Because of this it would be valuable to conduct an in-depth cost analysis.

In addition to designing the artefact, which is the result of this thesis, several other areas require further investigation before implementation can commence. In the short term, the picking policy needs to be clearly outlined and managed by the WMS to ensure coordination between the picking zones. Furthermore, a routing policy should be outlined. A prerequisite for successful implementation of the recommended storage allocation method, data regarding the fragility of SKUs needs to be entered into the system.

Long term, the use of AGVs needs to be thoroughly investigated to ensure that they align with the DC's operational needs and contribute to increased efficiency. Additionally, more detailed layout plans for the year 2034 should be developed. In these the design should be further adapted to meet evolving business requirements.

In conclusion, the continuous presentation and discussion of the artefact at Company Pie ensured its relevance. The short-term focus includes further outlining the picking policy and addressing data gaps related to SKU fragility. Long-term considerations involve evaluating AGV compatibility and developing detailed future layouts to adapt to changing business needs. These steps are essential for the successful implementation and sustained efficiency of the new DC configuration.

7.4 Contributions

This thesis contributes to practice by solving Company Pie's problem as stated in subchapter 1.3. A configuration for a new DC handing perishable goods was developed, considering contextual factors, and presented as an artefact. The artefact is compatible with the use of AGVs through the entire DC. Generalising the analysis conducted in this thesis, the context and configuration matrixes presented in Figure 3.4 can be applied to any warehouse configuration. Since context affects all warehouses (Faber, et al., 2013; Eriksson, et al., 2019; Kembro & Norrman, 2021), the matrixes can be used to determine which configuration is theoretically most suitable for the particular context in which the warehouse operates. This is done by placing the warehouse context along the context axes to determine which configuration is suitable.

This thesis did not discover anything new in terms of theory, but instead made use of theoretical frameworks and tools on a real-world problem and confirmed their usefulness in practice. The thesis confirms the contextual factors that Kembro and Norrman (2021) relate to task complexity challenges, as well as separation being a suitable configuration. In terms of contributions to academia, the thesis adds a new study within perishable goods warehouse design, which is an area with less coverage than the warehouse design of a regular distribution warehouse.

Lastly, in terms of the researchers own knowledge, the thesis deepened the authors understanding of contextual factors and how they affect warehouse configuration. Before starting this project, the authors were not familiar with the concept and gained much insight in how these factors affect a warehouse. The authors also hope that the approach of describing current configurations, identifying contextual factors and finally developing a configuration based on these, as seen in the framework for data collection and analysis, can be generalised to any warehouse configuration project. Furthermore, the authors hope that the contingency approach can be generalised in areas outside of warehousing and will be helpful in future projects.

7.5 Limitations and Future Research

This research is limited to a single company, representing a single instance, which constrains the generalisability of the thesis's conclusions and its contribution to broader theory. Additionally, the 20-week timeframe and scope impose further limitations. A detailed cost analysis, which could have provided a robust basis for evaluation, was not conducted.

The research scope is limited and does not address the receiving nor shipping operations. The efficiency and effectiveness of receiving and shipping processes is critical for of overall warehouse performance (Frazelle, 2016), and thus future studies need to be conducted to cover these operational processes. By complementing this thesis with analysis of receiving and shipping operations it would provide a more comprehensive understanding of a DC's material flow and thus enable the development of a more comprehensive configuration.

REFERENCES

Albers, M. J., 2017. Quantitative Data Analysis In the Graduate Curriculum. *Journal of Technical Writing and Communication,* 47(2), p. 215–233.

Aung, M. M. & Chang, Y. S., 2023. *Cold Chain Management.* Cham: Springer Nature Switzerland AG.

Baker, P. & Canessa, M., 2009. Warehouse design: A structured approach. *European Journal of Operational Research,* 193(2), pp. 425-436.

Bans-Akutey, A. & Tiimub, B. M., 2021. Triangulation in Research. *Academia Letters,* Issue 3392, p. DOI: 10.20935/AL3392.

Bartholdi III, J. J. & Hackman, S. T., 2019. *Warehouse & Distribution Science.* Atlanta: The Supply Chain & Logistics Institute H. Milton Stewart School of Industrial and Systems Engineering Georgia Institute of Technology.

Cardona, F., Rivera, L. & Jairo Martines, H., 2012. Analytical study of the Fishbone Warehouse layout. *International Journal of Logistics Research and Applications,* 15(6), pp. 365-388.

Cramer, D., 2003. *Advanced Quantitative Data Analysis.* Philadelphia: Open University Press.

de Koster, R., Le-Duc, T. & Roodbergen, K. J., 2007. Design and control of warehouse order picking: A literature review. *European Journal of Operational Reserch,* 182(2), pp. 481-501.

Denscombe, M., 2010. *The Good Research Guide For small-scale social research projects.* 4th Edition ed. Maidenhead: Open University Press.

Dissanayake, S. & Rupasinghe, T., 2021. *An Analytical Design & Optimization approach to enhance Warehouse Operations.* Moratuwa, Sri Lanka, IEEE.

Donaldson, L., 2001. *The Contingency Theory of Organizations.* Thousand Oaks, CA: Sage Publications.

Dresch, A., Lacerada, D. P. & Antunes Jr, J. A. V., 2014. *Design Science Research: A Method for Science and Technology Advancement.* Cham: Springer.

Eriksson, E., Norrman, A. & Kembro, J. H., 2019. Contextual adaptation of omni-channel grocery retailers' online fulfilment centres. *International Journal of Retail & Distribution Management,* 47(12), pp. 1232-1250.

Eriksson, E., Norrman, A. & Kembro, J. H., 2022. Understanding the transformation toward omnichannel logistics in grocery retail: a dynamic capabilities perspective. *International Journal of Retail & Distribution Management,* 50(8/9), pp. 1095-1128.

Fabio Benaglia, M. et al., 2024. Improving the picking efficiency of a cold warehouse to avoid temperature abuse. *The International Journal of Logistics Management,* pp. DOI: 10.1108/IJLM-01-2023-0044.

Frazelle, E., 2002. Warehouse Operations. In: *SUPPLY CHAIN STRATEGY The Logistics of Supply Chain Management.* s.l.:McGraw-Hill, pp. 224-272.

Frazelle, H. E., 2016. *World-Class Warehousing and Material Handling.* 2nd Edition ed. New York: McGraw-Hill Eductaion.

Glock, C. H., Grosse, E. H., Abedinnia, H., Emde, S., 2019. An integrated model to improve ergonomic and economic performance in order picking by rotating pallets. *European Journal of Operational Research*, 273(2), pp. 516-534.

Gu, J., Goetschalckx, M. & McGinnis, L. F., 2007. Research on warehouse operation: A comprehensive review. *European Journal of Operational Research,* 177(1), pp. 1-21.

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

Gue, K. R. & Meller, R. D., 2009. Aisle configurations for unit-load warehouses. *IIE Transactions,* 41(3), pp. 171-182.

Hagle, C., 2024. *LIDD.* [Online] Available at: https://lidd.com/warehouse-productivity-heat-maps/
[Accessed 24 May 2024].

Hassan, M., Ali, M., Aktas, E. & Alkayidc, K., 2015. Factors affecting selection decision of autoidentification technology in warehouse management: an international Delphi study. *Production Planning & Control,* 26(12), pp. 1025-1049.

Havner, A. R., March, S. T., Park, J. & Ram, S., 2004. Design Science in Information Systems Research. *Mis Quarterly,* 28(1), pp. 75-105.

Holmström, J., Ketokiivi, M. & & Hameri, A.-P., 2009. Bridging Practice and Theory: A Design Science Approach. *Decision Sciences,* 40(1), pp. 65-87.

Hwang, H., Oh, Y. H. & Lee, Y. K., 2004. An evaluation of routing policies for order-picking operations in low-level picker-to-part system. *International Journal of Production Research,* 42(18), pp. 3873-3889.

Kamali, D. A., 2019. Smart Warehouse vs. Traditional Warehouse - Review. *CiiT International Journal of Automation and Autonomous System,* 11(1).

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

Kembro, J. & Norrman, A., 2022. The transformation from manual to smart warehousing: an exploratory study with Swedish retailers. *The International Journal of Logistics Management,* 33(5), pp. 107-135.

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

Kembro, J., Eriksson, E. & Norrman, A., 2022. Sorting out the sorting in omnichannel retailing. *Journal of Business Logistics,* 43(4), pp. 413-678.

March, S. T. & Smith, G. F., 1995. Design and natural science research on information technology. *Decision Support Systems,* 15(4), pp. 251-266.

March, S. T. & Storey, V. C., 2008. Design science in the information systems discipline: An introduction to the special issue on design science research. *MIS Quarterly,* 32(4), pp. 725-730.

Nicolas, L., Yannick, F. & Ramzi, H., 2017. Optimization of order batching in a picking system with Carousels. *IFAC-PapersOnLine,* 50(1), pp. 1106-1113.

Nilsson, K., Ekman, N. & Löndahl, G., 2009. *Kalla fakta - allt du behöver veta om hanteringen av kylda och djupfrysta livsmedel,* s.l.: Djupfrysningsbyrån, Fredrik Strömblad.

Norrman, A. & Davarzani, H., 2015. Toward a relevant agenda for warehousing research: literature review and practitioners' input. *Logistics Research,* 8(1), pp. 1-18.

Pankok Jr., C. & Hoyleb, J., 2015. *Assessment of a Transfer Pick Pallet on Lower Back Biomechanics.* Melbourne, Proceedings 19th Triennial Congress of the IEA.

Petersen, C. G. & Aase, G., 2004. A comparison of picking, storage, and routing policies in manual order picking. *International Journal of Production Economics,* 92(1), pp. 11-19.

Petersen, C. G., 1997. An evaluation of order picking routeing policies. *International Journal of Operations & Production Management,* 17(11), pp. 1098-1111.

Piramuthu, S., 2022. Drone-Based Warehouse Inventory Management with IoT for Perishables. In: S. West, J. Meierhofer & U. Mangla, eds. *Smart Services Summit.* Gainesville, FL: Springer Nature Switzerland AG, pp. 13-21.

Quinn, W., 2023. *mdm Distriburion Intelligence.* [Online] Available at: https://www.mdm.com/article/tech-operations/operations/spaghetti-diagram-a-distribution-center-efficiency-weapon/
[Accessed 24 May 2024].

Richards, G., 2018. *Warehouse Management: A Complete Guide to Improving Efficiency and Minimizing Costs in the Modern Warehouse.* 3rd ed. London: Kogan Page Limited.

Romme, A. G. L. & Dimov, D., 2021. Mixing Oil with Water: Framing and Theorizing in Management Research Informed by Design Science. *Designs,* 5(1), pp. 1-16.

Romme, A. G. L., 2003. Making a Difference: Organization as Design. *Organization Science,* 14(5), pp. 558-573.

Roodbergen, K. J. & Vis, I. F. A., 2006. A model for warehouse layout. *IIE Transactions,* 38(10), pp. 799-811.

Rouwenhorst, B. et al., 2000. Warehouse design and control: Framework and literature review. *European Journal of Operational Research,* 122(3), pp. 515-533.

Rushton, A., Croucher, P. & Baker, P., 2014. In: *The handbook of logistics & distribution management.* s.l.:Kogan Page Limited, pp. 253-365.

Saunders, M., Lewis, P. & Thornhill, A., 2009. *Research Methods for Business Students.* 5th ed. Harlow: Pearson Education Limited.

Simon, H. A., 1996. *The Sciences of the Artificial.* 3rd ed. USA: The MIT Press.

Stragas, N. & Zeimpekis, V., 2011. Basic Principles for effective warehousing and distribution of perishable goods in urban environment: Current status, advanced technologies and future trends. . In: M. Bourlakis, I. Vlachos & V. Zeimpekis, eds. *Intelligent Agrifood Chains and Networks.* Chichester, West Sussex: Blackwell Publishing Ltd., pp. 39-65.

Thomas, L. M. & Meller, R. D., 2014. Analytical models for warehouse configuration. *IIE Transactions,* Volume 46, pp. 928-947.

Tremblay, M. C., Hevner, A. & Berndt, D. J., 2010. The Use of Focus Groups in Design Science Research. In: *Design Research in Information Systems. Integrated Series in Information Systems.* Boston, MA: Springer, pp. 121-143.

van Aken, J. E., 2004. Management Research Based on the Paradigm of the Design Sciences: The Quest for Field-Tested and Grounded Technological Rules. *Journal of Management Studies,* 41(2), pp. 219-246.

van Aken, J. E., 2005. Management Research as a Design Science: Articulating the Research Products of Mode 2 Knowledge Production in Management. *British Journal of Management,* 16(1), pp. 19-36.

van Aken, J. E., Chandrasekaran, A. & Halman, J., 2016. Conducting and publishing design science research: Inaugural essay of the design science department of the Journal of Operations Management. *Journal of Operations Management,* 47(1), pp. 1-8.

Vanickova, R., 2019. *Changes in Lifestyle of Population and Solutions in Logistics of Bakery Products: Practice in the Czech Republic.* 11th International Scientific Conference EMT 2019, Atlantis Press.

Yener, F. & Yazgan, H. R., 2019. Optimal warehouse design: Literature review and case study application. *Computers & Industrial Engineering,* 129(8), pp. 1-13.

Yildirim, N., Pushkarna, M., Goyal, N. & Wattenbeerg, M., 2023. *Investigating How Practitioners Use Human-AI Guidelines: A Case Study on the People + AI Guidebook.* Hamburg, Germany, ACM CHI Conference on Human Factors in Computing Systems.

Yin, R. K., 2018. *Case Study Research and Applications.* 6 ed. s.l.:SAGE Publications, Inc.

Yurtseven, C., Ekren, B. Y. & Toy, A. O., 2022. An Overview of Warehouse Operations for Cold Chain. In: F. Calisir, ed. *Industrial Engineering in the Internet-of-Things World.* Cham: Springer, pp. 161-175.

Zuin, S., Hanson, R., Battini, D. & Persona, A., 2020. Design of AGV systems in working environments shared with humans: a multi case study. *IFAC-PapersOnLine,* 53(10603-10608), p. 2.

APPENDIXES

Appendix I Interview guide for PDC and RDC

<u>About us:</u> We are final year students from LTH conducting a master thesis for Company Pie. Our specialisation is within supply chain management, and we are particularly interested in warehousing and material handling.

<u>The project:</u> The project has the objective of designing a warehouse configuration for the new DC. The main aim of this interview is to understand the current operations of the DC and contextual factors that affect the warehouse design.

<u>Introduction</u>

- Describe your role at Company Pie/Rho
- What is your educational background?
- What is your area of responsibility related to the project (new DC)?
  - Daily tasks? More long-term tasks?
- What experience do you have in the RDC?
  - How much insight do you have in different parts of the Company Rho organisation?
  - Are there any parts you have more, or less, insight in?

<u>Overall characterisation</u>

- What is the purpose of the DC? What do you want to achieve with the warehouse operations?
- What is the purpose of consolidating Company Rho in the NDC?
  - What is the vision with the move to NDC?
- What is your view/opinion on what should be changed when moving to NDC?
  - What do you think will be the largest change/challenge?
- Is there anything you would like to keep as is?
- To what extent will Company Pie and Rho be integrated? (for example orders, equipment, shared storage)
- What is the expected growth rate? (in terms of volume/pallet locations)

General flow

- How many products are there in storage and how varying are they in characteristics?
- Which ratio of these require special handling? (dangerous goods, fragile, temperature etc.)
- How often are new products introduced in the current DC?
    - Is this something that you plan on changing?

<u>Current situation</u>

Receiving

- What does the process of receiving goods look like? (until they are ready for put-away)
- In which handling unit do the goods arrive? (full pallet, container, mixed pallet)
- How are different temperature requirements handled during this stage?
    - Are there any SKUs requiring special handing?
- Which activities are performed by warehouse operators, and which are performed by the lorry drivers?
- Are there any special reasons for why the process is formed like this?
- Do you experience any challenges/problems with the process as it is today?
- Do you have any suggestions for how the process could be improved?
    - Is there anything you would like to keep as is?

Put-away

- Can you describe the put-away operation in the DC? (scanning routines, FIFO/FEFO etc)
- How are different temperature requirements handled during this stage?
    - Are there any SKUs requiring special handing?
- Are there any special reasons for why the process is formed like this?
- Do you experience any challenges/problems with the process as it is today?
- Do you have any suggestions for how the process could be improved?
    - Is there anything you would like to keep as is?

Storage

- What is the current storage policy? (random, dedicated, zone, class etc.)

- How are storage locations determined and how are the locations documented?
- What is the current warehouse capacity and utilization rate?
- Do you have a replenishment process?
    - If yes, how does it work?
- Do you experience any challenges/problems with the process as it is today?
- Do you have any suggestions for how the process could be improved?
    - Is there anything you would like to keep as is?

Picking

- Can you describe the picking operation?
- When do you receive the sales orders? When do you know what to pick?
- Is there any sorting of the orders after they have been picked?
- What is the current pick method? (Batching, zoning, one pick per person etc)
- How time demanding would you say this process is? (for example average time per pick)
- How are different temperature requirements handled?
- Are there any special reasons for why the process is formed like this?
- Do you experience any challenges/problems with the process as it is today?
- Do you have any suggestions for how the process could be improved?
    - Is there anything you would like to keep as is?

Shipping

- Can you describe the shipping process?
- How are orders "prepared" before leaving the DC?
    - How are they packaged?
    - Is there a staging area?
    - How long before departure are items staged (if staged)?
- Are the shipments scheduled?
- How are different temperature requirements handled?
- Which activities are performed by warehouse operators, and which are performed by the lorry drivers?
- Are there any special reasons for why the process is formed like this?
- Do you experience any challenges/problems with the process as it is today?
- Do you have any suggestions for how the process could be improved?

    - Is there anything you would like to keep as is?

Production

- Which operations are performed in the DC that can be considered separate from the ordinary warehouse operations?
- For all operations, do you differ between SKUs that are raw material for production?

KPIs

- How do you work with KPIs today? What is measured? How, how often, and why?
- Are any other metrics, beside the KPIs, used?

Warehouse design & resources

Layout

- Can you describe the layout of the DC in general terms? (zones etc)
- Why is the layout formed like this?
- How do you work with segregation in the layout to avoid contamination and mix-ups?
- Is the layout adapted to ensure that the cold chain is not broken? How?
- Do you experience any challenges/problems with the layout as it is today?
- Do you have any suggestions for how the process could be improved?
    - Is there anything you would like to keep as is?

Storage and handling equipment

- For Company Rho: is there any special equipment in RDC that is not used in PDC currently?
- Do you experience any challenges/problems with the equipment as it is today?
- Do you have any suggestions for how the process could be improved?
    - Is there anything you would like to keep as is?

Automation

- What is your view of automation in warehousing connected to this organisation?
- Is there any automation or other type of technology in any of the warehouse processes?
    - If yes, what type and to what degree? And why has this solution been chosen? Are there any advantages/disadvantages?
- Is there any area/process in which an automation solution would be advantageous?
    - Have you researched this, if no – why? If yes- what was decided?

WMS

- What WMS do you use?
- Which modules does the WMS have?
- Are there any plans on adding modules? Which?

Labour and other activities

- How many employees work in the DC? And do you have extra workers to handle seasonality?
- Do you have external workers? How do they work? (shift, hours)

Final question

- Is there anything else you would like to discuss?

Appendix II Interview guide for operators

About us: Present who we are, where we are from and approximate length of the interview.

About the project: We are writing a master thesis about warehousing and warehouse operations.

The focus and purpose of this interview: We want to understand how the warehouse operations function which a focus on which operations are time consuming or physically demanding, and if there are any suggestions on how to ease these. We also want to know if there is anything that works especially well.

About you

- Describe your role at Company Pie and how much experience you have in warehousing (both at Company Pie and other companies)
- What are your typical work tasks / areas of responsibility?
  - What are your daily tasks?
  - Do you have any more long-term tasks?
- Which parts of the warehouse operation do you have most experience in?
  - Are there any parts where you have less experience?

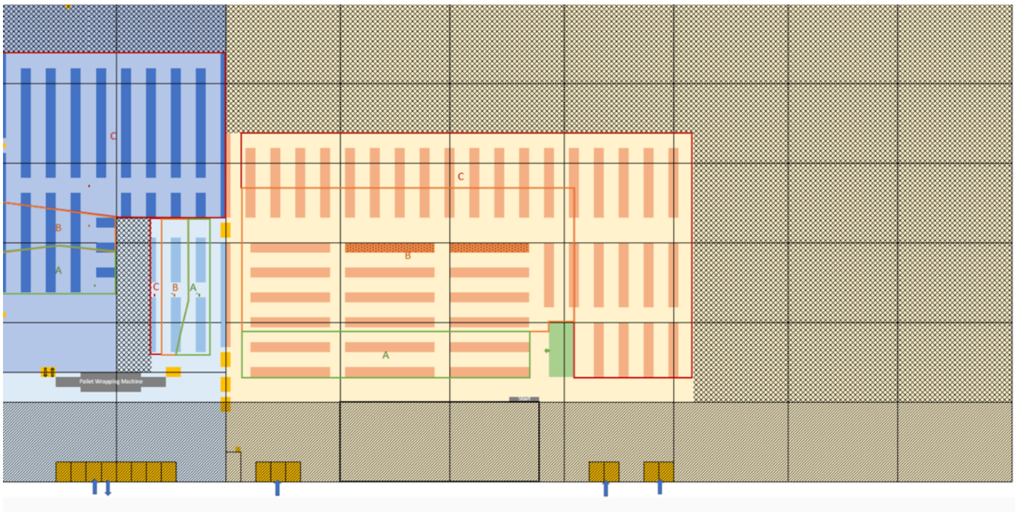
Interview questions

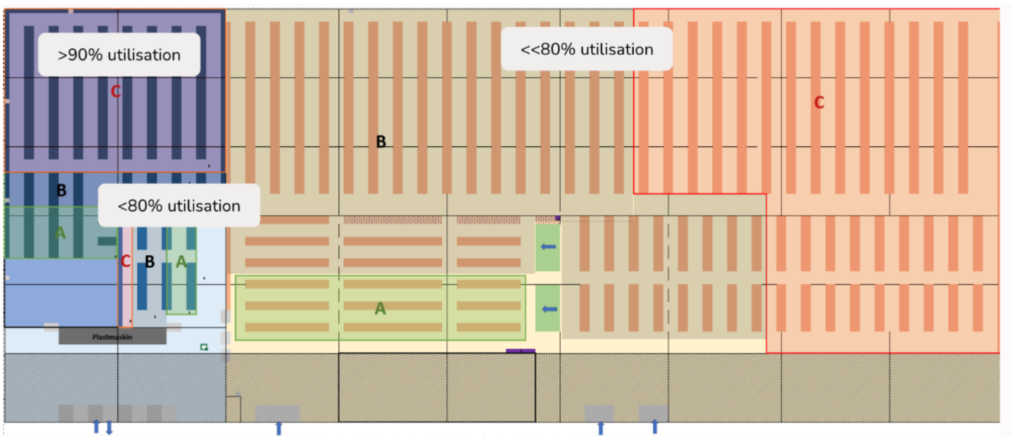
- Did you find it easy to learn your work tasks and the system? Why/ why not?
- Are there any work tasks that you experience as especially time demanding? Which and why?
- Are there any work tasks that you experience as especially physically demanding? Which and why?
- Are there any work tasks that you experience as especially cumbersome with a larger risk for mistakes? Which and why?
- Do you have any ideas on how you could improve any of your work tasks? If yes – which?
- Is there anything that you think works especially well in the warehouse?

Appendix III Guide for focus group

Introduction: The purpose of the focus group is to gain insight into your thoughts and reactions on the artefact. We will present what we have designed so far and then listen to your feedback and discussion on some chosen topics.

Short presentation of thesis purpose and scope. Then a short run thorough of the analysis to be able to present the artefact.





Opening question: What is your initial reaction to our artefact? Write down three thoughts on the paper in front of you. We will discuss your reactions.

Main questions

- What are the benefits and disadvantages of short side vs long side handling? What is your view on what is best for the new DC?
- Do you have any thought on how the DC could be divided into pick zones? Are there any logical divisions? Do you have any opinions about placing items in push-back racks?
- How can growth be handled? What are your ideas? Is there anything you believe will work better or worse (connected to the presented artefact).

Appendix IV Long side handing

The pallet is placed the long side parallel to the aisle so that the picker does not have to reach far inside the rack.

Appendix V Short side handing

The pallet is placed in the rack with the short side parallel to the aisle.

Appendix VI Data Request

Inventory levels per day over time for 2023: Date, storage location ID, ArticleID, number of pallets, atorage type, additional information about storage type.

Inventory levels for 3PL for 2023

SKU information: Article number, weight, dimensions, temperature, fragility, minimum order quantity, product group, shelf life.

Pick lists for 2023: Time and date for pick, article numbers, article name, number, created by, temperature zone, orderID.

Calculations of new inventory levels after consolidation: Storage – type, article ID, article name, number of pallets.