Reconfiguring a Unit-Load Finished-Goods Warehouse

A Design Science Study at Alfdex

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This master thesis project was conducted by two authors during the spring of 2024 as the final project of the master's program in Supply Chain Management (I), or Logistics and Production Management (M), at the Faculty of Engineering at Lund University. It was written at the Division of Engineering Logistics at the Department of Mechanical Engineering Sciences. This thesis has been a complete elaboration between the two authors. Each has been involved in every part of the process and contributed equally. The thesis is a design science study to propose a reconfiguration of the unit-load finished goods warehouse of Alfdex in Landskrona.

First of all, we would like to take the chance to thank our supervisor Joakim Kembro for guiding us throughout the whole process. This thesis would not be close to what it is today without him and his far-reaching expertise. We would also like to thank our seminar group for always providing constructive feedback and an outside perspective throughout the spring. Specifically, we would like to thank our seminar opponents, Matilda Muotka and Victoria Lindwert, for their time and willingness to discuss our work with us. The monthly meetings provided a valuable forum for exchanging ideas and discussing challenges, the significance of which for this thesis cannot be overstated.

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ABSTRACT

Title	Reconfiguring a Unit-Load Finished-Goods Warehouse
Authors	Jakob Bjarke & Oliver Elftonsson
Supervisor	Joakim Kembro, Department of Industrial Management and Logistics, Faculty of Engineering, Lund University
Problem formulation	Since moving, Alfdex has experienced increased demand while the Finished Goods Warehouse (FGW) has remained unchanged. This has caused challenges such as insufficient capacity, double handling, operational inefficiency, and inefficiency in maintaining First-In-First-Out (FIFO).
Purpose	The purpose of the thesis is to *propose a complete reconfiguration for the FGW at Alfdex.*
Research objectives	RO1: Understand how warehouse configuration affects performance. RO2: Investigate the current state of the FGW to identify wastes, contextual factors and requirements for the new configuration. RO3: Design a new configuration for the FGW and evaluate the expected performance.
Methodology	The study uses a design science approach. The methodological framework outlines the thesis process, including key elements such as literature review, external company visits and data analysis. The analytical framework summarizes the theoretical background, covering the contingency approach, the warehouse configuration framework, and analytical tools. These frameworks are combined in the thesis framework, highlighting important methodological elements.
Findings	The current state was thoroughly investigated. Divided into five categories, 16 design propositions were formed. The propositions and their implications for configuration elements were detailed. Combining the design propositions generated a new configuration.
Conclusion	The new configuration fulfills the requirements and improves key performance indicators. Capacity increases, time for daily operations is nearly halved and system support that ensures FIFO is introduced. The proposed configuration received positive feedback from Alfdex employees at a validation workshop. Thus, the purpose to *propose a complete reconfiguration for the FGW at Alfdex* is fulfilled.
Keywords	Warehousing, Warehouse Configuration, Contingency Approach, Contextual Factors, Design Science, CAMO.

ABBREVIATIONS

AGV	Automated Guided Vehicle
DS	Design Study
ERP	Enterprise Resource Planning
FIFO	First In First Out
FGW	Finished Goods Warehouse
MTO	Made To Order
MTS	Made To Stock
NVA	Non Value-Adding
NNVA	Necessary but Non Value-Adding
SKU	Stock Keeping Unit
RO	Research Objective
RMW	Raw Material Warehouse
VA	Value-Adding
WMS	Warehouse Management System

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1 INTRODUCTION

This section aims to give a thorough introduction to the thesis project. Initially, the background is introduced in general terms. A description of the case company and problem of the thesis follows. Furthermore, the purpose of the project and the corresponding research objectives are presented. Lastly, the main focus and delimitations are presented.

1.1 Background

Warehouses are irreplaceable in companies' business logistics systems and play vital roles in their success (Sienera, Octavia & Winoto, 2022). The supply chain disruptions in the wake of the pandemic have accentuated the role of warehousing (Min, 2023). From a practical business view, warehouses are important in two distinct aspects, costs, and performance. The logistics costs, as part of production costs, are often extensive (Rouwenhorst et al., 1999). Warehouses are expensive, as they require labor, land, information systems as well as storage and handling equipment (Bartholdi & Hackman, 2019). However, their existence is warranted. Effective warehouse operations decrease transportation costs and increase customer service by meeting supply with demand and consolidating shipments (Bartholdi & Hackman, 2019). The warehouse is an essential node in the distribution network where the warehouse operations play a crucial role for efficiency and effectiveness of the supply chain (Rouwenhorst et al., 1999).

There is no perfect approach to the work of designing a new warehouse configuration. According to the increasingly popular contingency approach, organizations should match structures and processes to their internal and external environments to improve their ability to perform. However, there is no absolute right way since it depends on the context (Kembro and Norrman, 2021). To develop a successful configuration, the combination of operations, design and resources of the warehouse must be investigated. The contingency approach highlights that taking the contextual factors into account is essential and linked to better performance (Kembro and Norrman, 2021; Faber et al., 2018). Therefore, a holistic perspective is necessary to establish the most appropiate solution for the specific case.

To take contextual factors into account, the current situation must be investigated with analytical tools. In this thesis the analytical tools consist of activity profiling and lean tools. Activity profiling involves measuring and analyzing warehouse activities to understand how the warehouse functions (Bartholdi and Hackman, 2019). Specifically, it aims to investigate contextual factors. To minimize expenses in a warehouse, it is important to allocate the resources wisely. By utilizing lean tools, inspired by the "integrated approach for warehouse analysis" by Dotoli et al. (2015), the wastes and problems of the Finished Goods Warehouse (FGW) at Alfdex are investigated. The analysis affects the proposed new FGW configuration by enhancing performance through reducing waste and considering the contextual factors.

The expectations of the warehouse have shifted towards increased automation and digitalization. This has led to prominent companies increasingly investing in automation for their warehouses (Kembro & Norrman, 2022). Technological progress has given birth to new concepts such as "Warehousing 4.0" and "Smart Warehousing" that are emphasizing the importance on automation and digitalization (Min, 2023; Perotti et al., 2022). In a warehousing context this translates to increased expectations on the information systems as well as an increase in the use of Automated Guided Vehicles (AGV). The use of AGVs has been seen to increase reliability and availability of operations and decrease operating expenditures, although it involves high investment expenses (Ullrich, 2023).

Warehouses can be designed and organized in several ways depending on the attributes of the Stock Keeping Unit (SKU) (Bartholdi & Hackman, 2019). While warehousing in general, and omni-channel- and distribution warehouses in particular, are being increasingly researched, there is a lack of studies investigating how to redesign a warehouse configuration for a unit-load FGW in a production setting. This thesis aims to fill this gap and thereby contribute to research.

1.2 Case Company

Alfdex is a company that manufactures crankcase gas-separators for diesel engines, with its headquarters and production facility situated in Landskrona. The company was founded in 2002 as a joint venture between Alfa Laval and Haldex. However, the company is currently owned by Alfa Laval and Concentric, which took over Haldex's share in 2011. Additionally, Alfdex has a production facility in Kunshan, China, and a research and development site at Tumba, Sweden. Alfdex is an environmentally conscious company with the stated purpose of making the world "Greener by g-technology". Their main product, the g-cleaner, separates the contaminated ventilated crankcase gases from returning to the inlet of the combustion engine or being emitted to the environment. Alfdex employs a combination of a Make-To-Order (MTO) and Make-To-Stock (MTS) production strategy, where products are produced after customer orders in general, but the shipping of the individual produced SKU is not determined at the time of production. The FGW uses the First-In-First-Out (FIFO) principle for their finished goods, in accordance with industry standards.

1.3 Problem Formulation

The configuration of the FGW has to be investigated to increase the space utilization. Alfdex relocated to their current location in 2017, due to outgrowing the capacity at the former location. The intended maximal capacity for the current location was to produce 650 thousand separators per year, last year they made 850 thousand. Due to increasing demand from the customers, and winning large contracts, the production volume has increased rapidly. While sales have grown, production has incrementally improved. Consequently, the production area has been increasingly cramped as new production lines have been added. Additionally, there are plans to implement a new production line. Thus, Alfdex has requested that given that the reconfiguration can accommodate the required capacity and adequate operations, a part of the FGW area be dedicated to being a production area. This is achieved by more effectively utilizing the area in the FGW.

The FGW has remained unchanged, in contrast to the production, which has led to capacity issues affecting operational performance. Along with the increase in demand, the product assortment has also expanded. SKUs are currently being stacked and placed in a bin on the floor in the FGW. While this simple strategy effectively utilizes the floor space, it does not effectively use the height of the warehouse building. This strategy, in combination with increased demand, has led to limited storage capacity, especially when there are demand peaks. The present capacity delimitations negatively affecting operations, especially through double handling. This is especially accentuated in the inefficiency of the picking process, as multiple-deep bins combined with FIFO, is an unfavorable combination causing double handling.

The information systems, guiding the employees in the FGW, has to be improved to ensure FIFO and improve operations. With the current setup the Warehouse Management System (WMS) only identifies one stock location in the FGW. This leads to avoidable administration, particularly in the shipping department, as well as inability to optimize pallet storage, since pallets are not connected to pallet positions. Furthermore, the shipping coordinators do not have guidance in the picking process to help them ensure FIFO, which is done manually. To summarize, the FGW faces several issues that cause spillover effects on several departments. Hence, the configuration of the FGW at Alfdex has to be improved to increase the capacity, improve operational performance and ensure FIFO through guidance from information systems.

1.4 Purpose & Research Objectives

The purpose of the thesis is to *propose a complete reconfiguration for the FGW at Alfdex.* To reach this goal three Research Objectives (ROs) have been formulated. These objectives will serve as a guide throughout the thesis. The research objectives, and their connection to the purpose, are illustrated in *Figure 1.1.* Furthermore, they are listed, with corresponding explanations, in the text below.

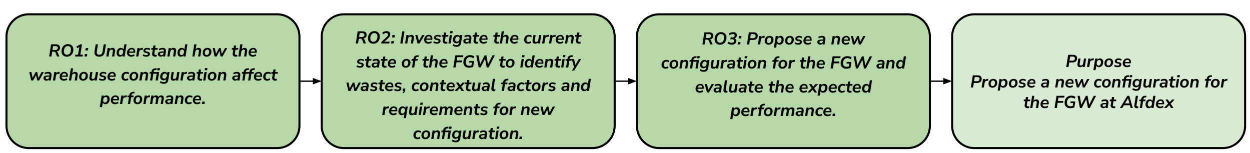

Figure 1.1: Research Objectives and Purpose of the Thesis Project.

RO1: Understand how the warehouse configuration affects performance.

This knowledge will be obtained through two sources, a literature review and company visits. The literature review aims to provide a theoretical basis for the proposed solution. This includes how the contingency approach, and warehouse configuration, including operations, design, resources, and contextual factors, affect performance. Additionally, company visits are conducted to gain inspiration and practical insights for the design of the new configuration. The focus of the company visits is to investigate how contextual factors and the use of automation, especially AGVs, are utilized to improve warehouse performance.

RO2: Investigate the current state of the FGW to identify wastes, contextual factors and requirements for new configuration.

This research objective aims to map out the current state of the FGW. This includes a collection of qualitative data, such as interviews with employees, as well as quantitative data, gained from the Enterprise Resource Planning system (ERP), and measurements done by hand. Analytical tools will be used to analyze the current state, which includes activity profiling- as well as lean tools. The activity profiling tools include the ABC-analysis and Heat Maps, employed to investigate contextual factors. The lean tools used as a part of the integrated approach to warehouse analysis include the Value Stream Map, Spaghetti Diagram and Muda Matrix. These investigations will identify possibilities of improvement for the FGW configuration.

RO3: Design a new configuration for the FGW and evaluate the expected performance.

The main part of the master thesis is to propose a new configuration. The current FGW has a simplistic configuration, which leads to waste in the form of inefficient operations. Additionally, the current capacity is insufficient during peaks of stored SKUs. Therefore, creating a new layout will enhance efficiency and give rise to a sustainable solution. The potential use of AGVs, different types of racks, forklifts and scanners are other aspects of the proposed configuration. To show that the proposed solution will lead to improvements, the proposal will be evaluated using a set of selected KPIs. The KPIs to be investigated for operations include pallet-flag picking, SKU-picking, loading, and total operations time. For the design, the KPIs focus will be on pallet face availability and pallet position utilization.

Purpose: Propose a complete reconfiguration for the FGW at Alfdex.

The main purpose of the thesis is to provide a new configuration for the FGW. The propositions should cover all aspects of a configuration, including the operations, design & resources of the new warehouse.

1.5 Focus & Delimitations

The thesis will have its focus on the FGW. It investigates the SKUs from the moment they pass the door to the FGW to the point that they leave, as illustrated in *Figure 1.2*. Thus, the Raw Materials Warehouse (RMW) and production facility are not part of the scope. The pallets arrive at the FGW from production, meaning that the first operation is receiving. The pallets are then put in temporary stock, located at the entry of the FGW. Then the SKUs are placed at the main stock, which consists of storage bins dedicated to specific customers. Lastly, pallets are placed in the loading area one day before being shipped to customers.

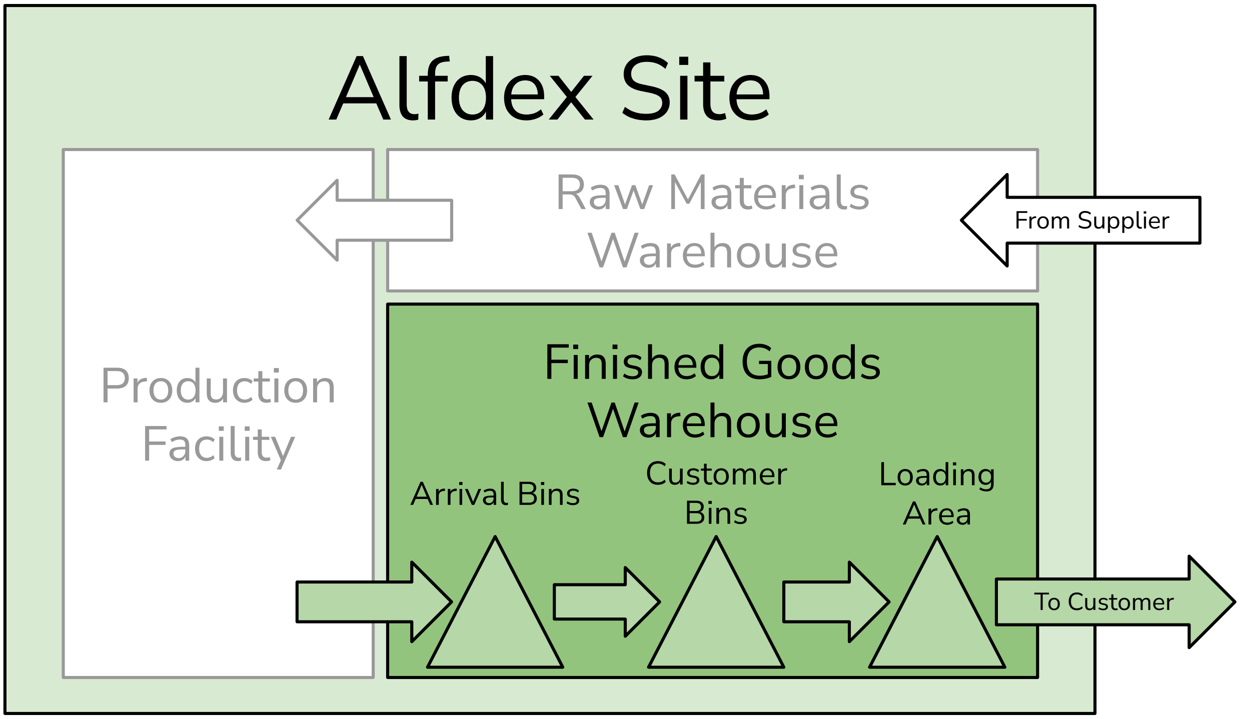

Figure 1.2: Focus of the thesis.

The delimitations of the thesis concern the aspects that will not be considered in the project. This includes constraints, both strategical and physical. The delimitations are listed below.

Delimitations

- *Production strategy*: The production strategy, including quantity and frequency of the batches, is out of the scope of the thesis.
- *Storage strategy*: The company strives to keep a certain amount in stock of each product. This strategy is not considered.
- *Information systems*: The requirements that the configuration has on the information systems are to be determined. However, a specific information system, WMS or module is not investigated.
- *Budget constraint*: There is no specified budget constraint. However, the proposed configuration should be cost-efficient to be realistically considered. The report does not contain any budgeting or financial recommendations.

2 METHODOLOGY

This section of the report is dedicated to outlining the various theoretical methods and approaches, as well as when they were employed. Initially, it outlines the strategy, process, and design of the research. The literature review follows. The data collection consisting of observations, interviews, secondary data and company visits is then presented. The design process is introduced. How the research quality of the project is ensured is touched upon. Lastly, the methodological framework, summarizing the section, is presented. The outline of the method section is illustrated by Figure 2.1. In the figure the dashed lines illustrate how sections build on earlier section, and the full lines that section contributes to the methodological framework. Each part of the methodology outline is presented in greater detail in the following sections.

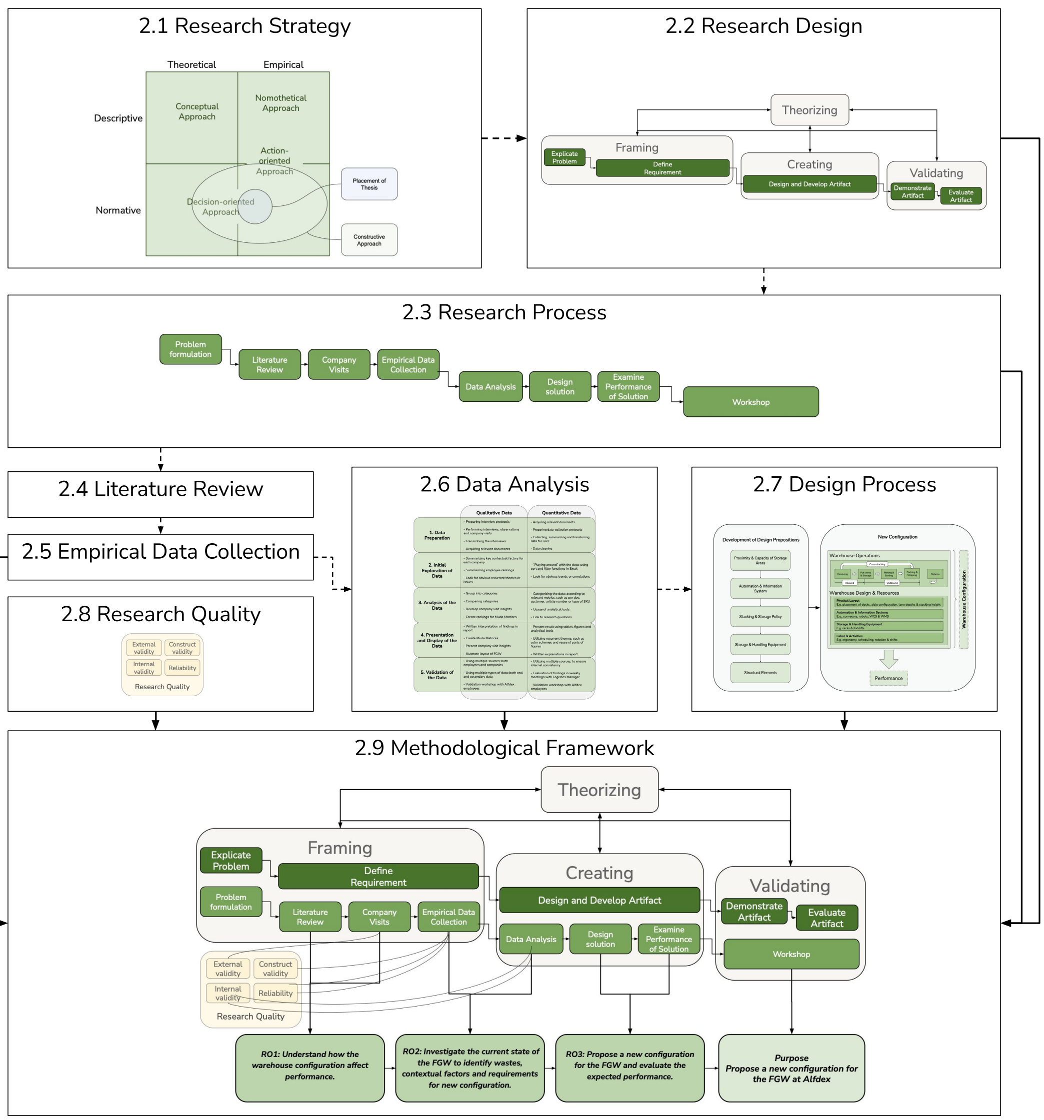

Figure 2.1: Outline of disposition for the methodology section.

2.1 Research Strategy

Research strategy refers to the comprehensive approach or plan that guides the overall direction and methodology of the research project. It is divided into research approach and choice of study. The approach connects the study to the established researched approaches and labels it according to the aim and the type of data and references that was collected during its proceeding. The choice of study expands on the different kinds of studies that are usually employed for master's theses in this field and uses the previously defined approach to justify the particular choice.

2.1.1 Research Approach

There are several different ways in which a master thesis can be approached. In their work outlining the Constructive Approach, Lukka et al. (1993) introduced a matrix classifying several different approaches from a scientific perspective. The axes contain empirical vs. theoretical and descriptive vs. normative respectively and are commonly referred to as the Established Accounting Research Approaches. The matrix, and the placement of this thesis, is illustrated in *Figure 2.2*. The motivation for this placement is discussed below.

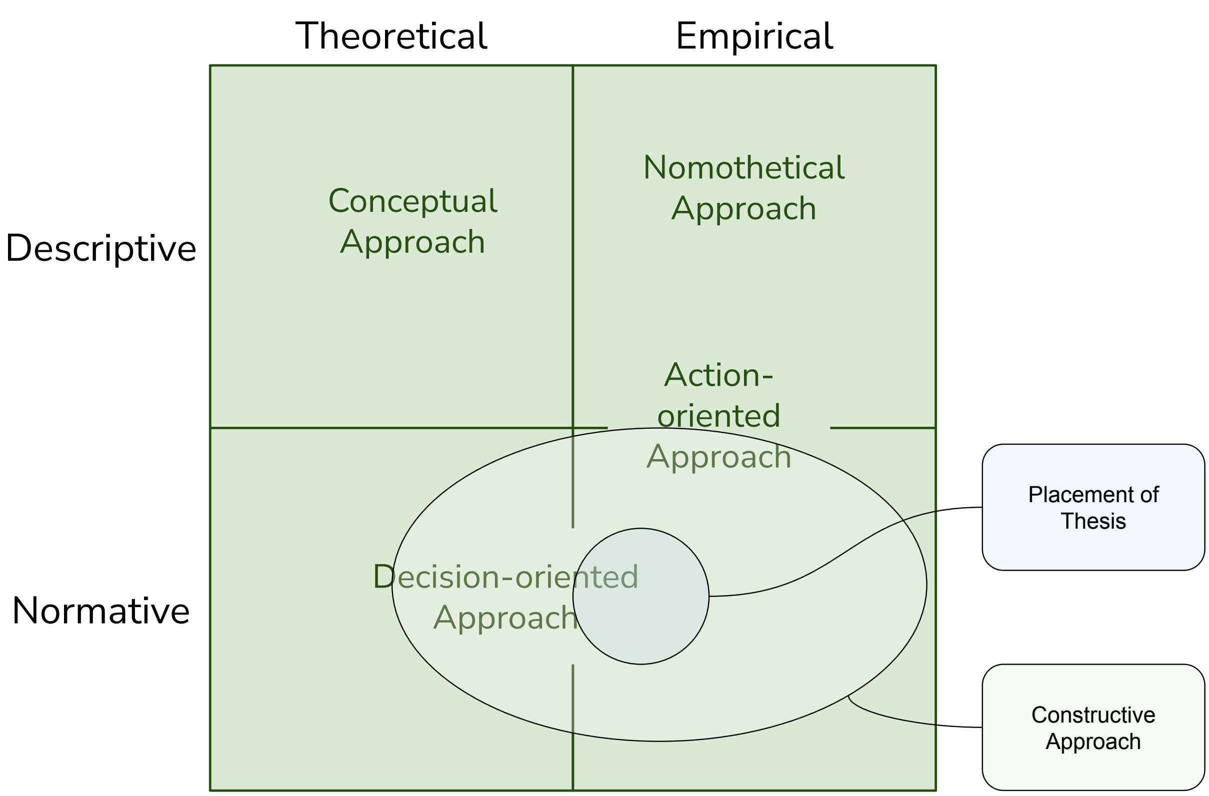

Figure 2.2: Placing this master thesis within the matrix of established research approaches, adapted from Lukka et al. (1993).

The covered approaches include the nomothetic approach, where phenomena such as actions or principles are attempted to be described by generalization to a field or group of people. This approach usually involves quantitative methods such as surveys, experiments, or other forms of analyses. The conceptual approach also endeavors to create an understanding of said principles or circumstances by using the lens of previously established principles or reasoning. Therefore, it does not rely on empirical data to provide new scientific contributions but rather by finding and using suitable and topical references.

The decision-oriented approach introduces the normative approach where the aim is to assist decision makers by portraying for example resource allocation or what data suggests is rational. It is in the middle of theoretical and empirical, meaning both reasoning and empirical data gathering are typically used as foundation. This as decisions should not be entirely based on frameworks and can benefit from being validated by data. The action-oriented approach differs from the nomothetic approach in that it relies less on collected data and more on historically similar discoveries. The approach is not fully normative but often includes assistance for future decisions or contains proposals for change.

The constructive approach draws from the normative principles of seeking to assist in decision making while also integrating empirical data into the decision. Having access to data is a prominent aspect of the constructive approach and was induced as a response to a highly theoretical decision-oriented approach that does not take use of all available data.

The thesis leans more towards empirical than theoretical. The research consists of both reasoning based on prior knowledge and analysis of collected data. Literature and evaluation of previous implementations provide the basis for reasoning while collected data highlights areas of improvement. An element of theorizing is included both for the scientific contribution and to increase the reliability of the proposed solution and practical contribution.

In terms of normative or descriptive, the thesis is more towards normative. Finding areas of improvement in the process and looking into implementable solutions is outlined as a main objective of the study through RO3. The main deliverables are highly normative. Just as for the theoretical and empirical above there is also the need for the study to be of deductive and descriptive nature and contribute to the field of logistics through generalizations. Combining the two assessments, using the metrics of the established research approaches, this master thesis is placed according to *Figure 2.2*.

The placement of the thesis indicates that a combination of a decision-oriented and constructive approach is suitable. The main attribute of these approaches is that they aim to assist decision makers. A solution-oriented type of study type that has the normative element of the decision-oriented approach but is based primarily on empirical data like the constructive approach, hence creating a link to reality, is the design science study.

2.1.2 Choice of Study

Design science highlights problem-solving and emphasizes the importance to "finding a means to an end" (Holmström et al., 2009, March & Smith, 1995). For the study to be allowed to be associated with design science it must contain an "artifact", a solution to the predicament it addresses. In this context, design science is normative, as devised artefacts show how a system ought to be (Simon, 1996). This means the study cannot limit itself to problem solving processes, or the processes it examines, but include how to implement the artifact. Holmström et al. (2009) describes the phenomenon of exploratory research, of which design science is a part, as being "artificially created" specifically for the study, in contrast to it being "out there". Focus also lies on pragmatic problem solving, rather than theoretical and predictive approaches.

The design science approach has been chosen as research strategy for this thesis. The deliverables and research objectives imply that the key focus is to provide the case company with a plan on how to improve their current operations. The phenomenon of the study has been as such selected subsequently to the initiation of the research and could not be clearly defined until an analysis of the current situation had been concluded. While there is knowledge to gain from analyzing current operations, and a potential implementation plan, the main value is not theoretical but normative, as previously stated in *Subsection 2.1.1*. All these aspects strongly suggest that design science is a suitable form of study of this master thesis.

2.2 Research Design

Research design refers to the overall plan for outlining the process and structure of the study with emphasis on how to evaluate knowledge and process information. The first part introduces the CAMO-format for evaluating and understanding the dimensions of knowledge. The second looks at the method framework that describes how to work on the artifact.

2.2.1 Foundations of Design Science

The research design is linked to the CAMO, *Context-Agency-Mechanism-Outcome*, format situated in the domain of DS and introduced by Romme and Dimov (2021). The authors asserts that the format describes each dimension of information needed to apply theoretical frameworks in a real life setting with the purpose of gaining both theoretical knowledge and acting as foundation for future implementation. The authors further claims that CAMO distinguishes itself from its predecessor, the CIMO format that considers the *intervention*, the action, which leads to a *mechanism*. CAMO instead includes the *agency* dimension which revolves around actors' capacity to initiate actions. Since actors' capacity in the given context is more crucial than the action itself, CAMO is more relevant for this thesis. There are also other variants of the format adapted specifically to ventures such as entrepreneurship, where the format is applied directly on an acted upon opportunity (Van Burg & Romme, 2014). Consequently the CMO-format skips *agency* to link *context* directly with *mechanism*. Each part of the CAMO-format is detailed below.

Context The contextual dimension within CAMO delves into how specific conditions influence some of the fundamental organizational features. These conditions constitute the "materials" that dictate the choices and behaviors of individuals within the organization, and which of whom the structure is an extension of. Although individuals are free to act as they see fit, the context can provide direction for those actions or restrict them from others.

Agency This aspect highlights the capacity of different actors to initiate actions in a given context. It also takes into consideration the impact those actions may have by looking at the predefined context. The agency dimension is not limited to a specific period of time and usually looks at past and future operations. Agency is defined by a set of factors that have a close link with the social arrangements in the context.

Mechanism The mechanism dimension captures a "theory of change" by attempting to highlight the mechanisms present in the context. It can be difficult, in some cases near impossible, to detail the mechanisms as they can vary in nature and observability. Additionally, their impact can easily be over- or underestimated due to challenges with identifying other mechanisms or missing correlation of mechanisms. Analytical and conceptual frameworks are generally needed as a part of this aspect for identification and analytical purposes.

Outcome The outcome is the end result of the aforementioned aspects. The general thought is that a certain kind of agency in a specified context activates mechanisms, sometimes hidden, that lead to an outcome. The outcome consists of both intended and unintended outcomes and can be captured through a multitude of different values and processes throughout the organization. The social mechanisms that shape the observed results are also highlighted. The CAMO format can be employed in the study to retrieve knowledge from the information of relevant literature. However, it may also be applied as a format of inquiry when evaluating all information gained in communication, such as interviews, tours, and surveys at Alfdex and other company visits. The CAMO format explicitly recognizes the complexity of underlying mechanisms, which suggests a method of analyzing collected information should focus on outcome in terms of agency and context rather than mechanisms.

2.2.2 Design and Science Framework

A framework introduced by Romme and Dimov (2021), referred to as the Design and Science framework, is used to widen the perspective to the application of knowledge in processes of the design study. The framework addresses the distinction and connection between design and research and places the CAMO-format accordingly. The framework contains the four constructs: *framing, creating, theorizing,* and *validating* which is illustrated in *Figure 2.3*.

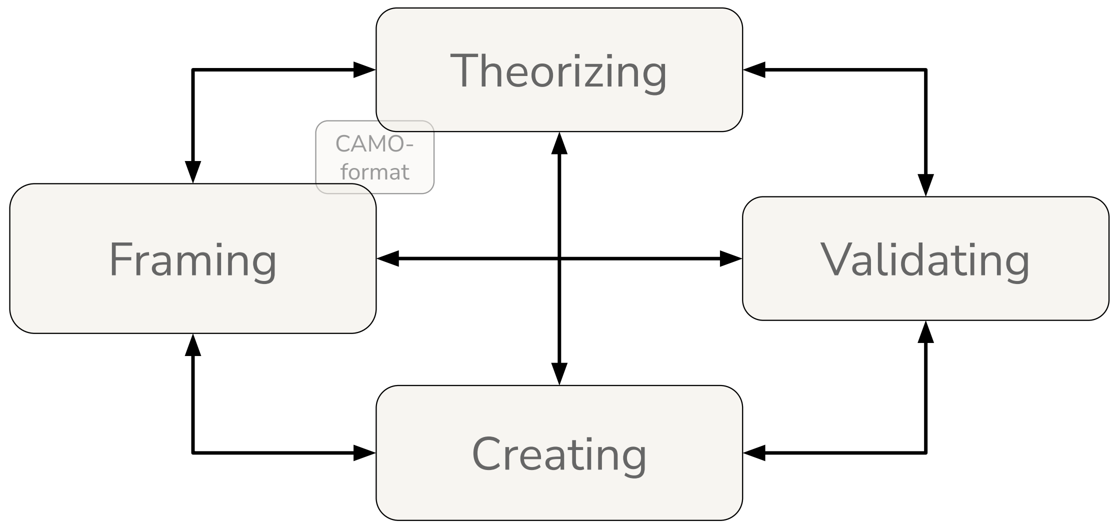

Figure 2.3: Design and Science Framework, with CAMO. Based on Romme and Dimov (2021).

The purpose of the Design and Science framework is to create a clear link between the current situation and "what could be" (Romme & Dimov, 2021). As an extension, Le Moigne (1994) claims that the artifact exists in neither the natural nor the artificial world. It is instead an interface, or intersection, of those that constitutes the artifact (Le Moigne, 1994).

Framing refers to the exploration of the set, the *context*, which defines the problem and solution space. These two are directly linked as identifying a larger problem space supports a larger solution space (Carlgren et al., 2016). These spaces are meticulously laid out considering everything from separate occurrences to devising constructs explaining widespread phenomenon. This constitutes looking at both *agency* and *mechanism*. Framing synthesizes with beliefs that theory development is an act of discovery through creativity.

Creating introduces the act of envisioning and outlining artifacts, which corresponds well with both problem and solution space. Just as the problem space has an unlimited number of configurations, there are no boundaries on the form that artifacts can take. Romme and Dimov (2021) expressed the following as some examples on artifacts found in literature; strategy practices, intervention strategies and decision-making tools. Applying the design principles to the creative process enables nonlinear thinking, which is suited to tackle modern business-problems (de Villiers, 2022). Framing and creating often go together with many iterations between the two notions and redefining the spaces with continuous discoveries.

Theorizing connects the design process with developing key concepts and models that can be used as reference for future design processes. It builds on the creative suggestions produced in framing and creating to show how theory has been applied to create a proposition of normative value. The value of the application of theory with a normative purpose has become increasingly recognized (Suddaby, 2014). Although delivering theoretical output rarely is a key goal of DS-studies, theorizing is generally engaged in to some extent (Romme & Dimov, 2021). This generalization of outcomes links to the *outcome*-part of CAMO.

Validating targets evaluation of devised artefacts. Venable et al. (2012) describes the necessity of evaluating all aspects, or components, of the solution on their respective significance. Decoupling the components allows for individual evaluation, making the validation process iterative, creating a clear link to all steps in the framework. This highlights potential streamlining of the design process if the designers are aware of evaluation (Venable et al., 2012). In terms of testing, the solution can be tested artificially, for usability and practicality. Alternatively naturalistically, for validity and generalizability (Romme & Dimov, 2021).

2.2.3 Method Framework for Design Science

The method framework for design science, introduced by Johannesson and Perjons (2021), is to be used in conjunction with the design science frameworks to construct a study that adheres with design science principles. It consists of five main segments that together form a solid structure. The framework's purpose is to outline the steps required to turn the initial problem into an evaluated artifact. The full sequential proceeding is shown in *Figure 2.4*.

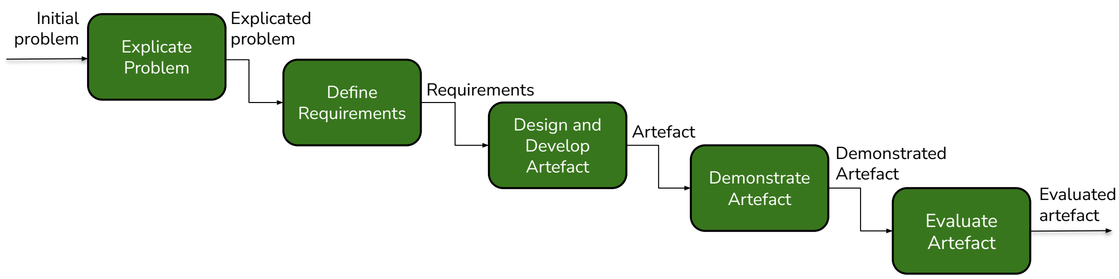

Figure 2.4: Overview of the method framework for Design Science, adapted from Johannesson and Perjons (2021).

Explicate problem This activity within the framework involves a thorough investigation and analysis of the problem. It requires a precise formulation of the problem, underscoring its significance in the research field (Johannesson and Perjons, 2021). Peffers et al. (2020) claim that proving its value motivates the audience and researcher to pursue the artifact and increases acceptance and understanding of the reasoning behind it. In terms of knowledge, this segment covers both the understanding of the problem and the need it creates. Relevant data for the solution is collected. This directly relates to the problem and solution space, hinting at the connection to the *context* of the CAMO-framework and *framing*.

Define requirements Defining the requirements of the to-be proposed artifact, in addition to potential delimitations, is crucial within the framework. It transforms the identified problem into specific demands for the artifact. De Sordi (2021) states that the different aspects of the artifact should be addressed at an early stage. The first such aspect is whether the artifact should be a new function or a sub-function to an existing one. The second is what potential operational, financial, or qualitative performance, and to what degree, should be improved by the solution. If an initial problem leads to several artifacts, each needs thorough analysis. In addition to creating further understanding of the problem and solution space, linked to *context* and *framing*, it also looks ahead to *agency, mechanism and outcome.*

Design and Develop Artifact This activity constitutes the creation of the artifact to address the explicated problem and fulfill the defined requirements. This process includes determining functionality and structure before moving onto creating the artifact. Knowledge and theory brought forward at earlier stages of the study are central to moving from objectives to design (Peffers et al., 2020). In terms of CAMO this stage looks at all aspects with particular emphasis on the *agency and mechanism* parts, assuming the problem has been clearly defined. It is close to *creating* in the Romme and Dimov framework.

Demonstrate Artifact Demonstrating involves presenting the artifact in ways that portray how it operates within the confines of the requirements to solve the explicate problem. The demonstration is often referred to as "proof of concept" (Johannesson and Perjons, 2021). The showcasing depends on the properties of the artifact and can be realized in several ways, ranging from a visual representation of physical movement to performance of a subsystem. The demonstration increases the feasibility of the artifact and ensures authenticity. It is closely related to the *outcome* feature of CAMO and attempts to generate understanding of the system and the artifact by exemplifying in an admissible context.

Evaluate Artifact The final part of the framework assesses to what extent the artifact solves the problem. Since evaluation validates the artifact, a numerical method is typically used. In addition to looking at the must-improve measurements circumscribed in the definition of the requirements, the artifact can also impact other aspects. If so, it can be beneficial to observe the impact on some contextually used measurements, such as KPIs. The requirements for utilizing the artifact, both in terms of knowledge, agency and physical constraints, should also be considered. It is clearly associated with *validating* but extends beyond the previously mentioned frameworks. In terms of CAMO, it depends on knowledge generation, and for Romme and Dimov, on how much ties back to the design process of the artifact.
There are several ties between the CAMO framework, dividing design research into framing, creating, theorizing and validating, and the method framework. By picking out the strongest connections, as mentioned in the previous sections, the frameworks can be combined. The connections are illustrated in the Design Science framework, see *Figure 2.5*. This constitutes a basis for better understanding the relevance of each of the performed activities, and which design science aspect they are affiliated to.

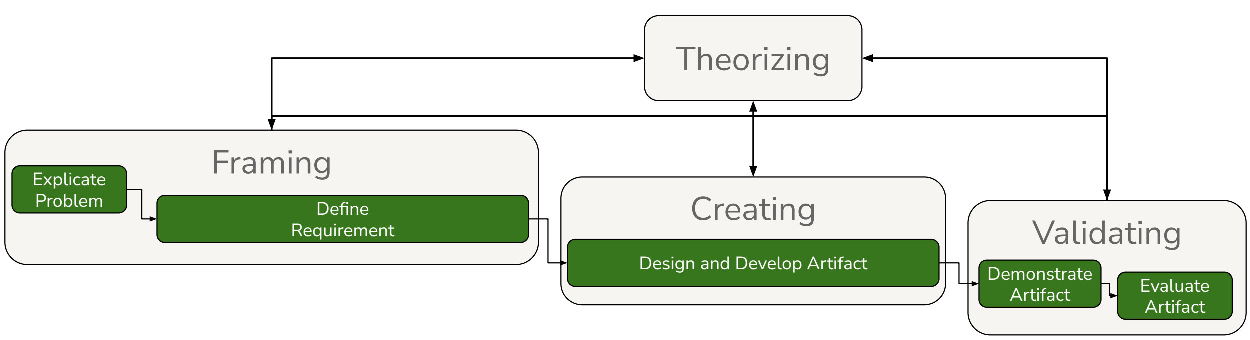

Figure 2.5: Design Science Framework, combining the work of Johannesson and Perjons (2021) and Romme and Dimov (2021).

2.3 Research Process

The research process consisted of all activities that were performed to be able to reach the deliverables. The activities that are were performed in this specific thesis project, with a link to the method framework, are portrayed in *Figure 2.6*.

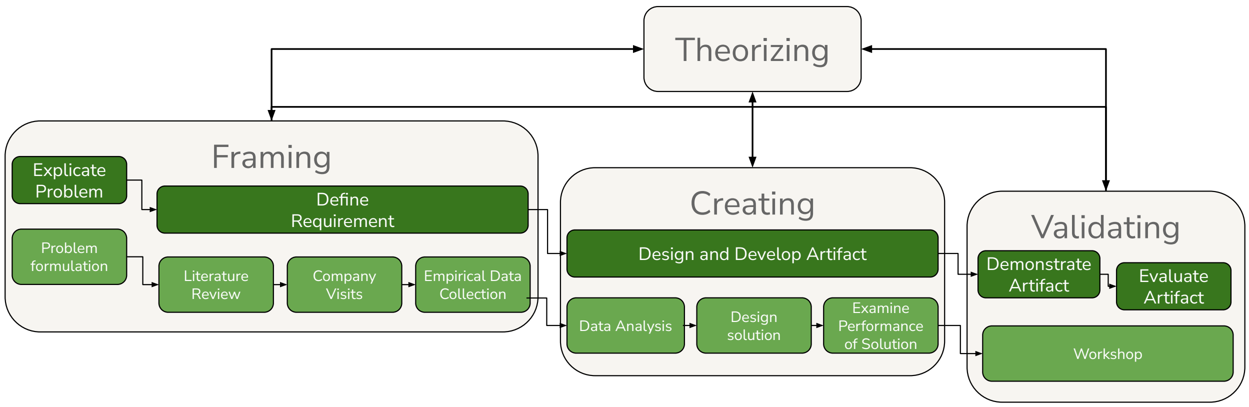

Figure 2.6: Overview of the activities that constitute the study.

The activity that was the most heavily tied to outlining the explicated problem is the problem formulation. In practicality this entailed the initial company visit in conjunction with previous and latter communications to ensure a correct formulation.

Defining the requirements for the artefact was linked to the literature review, company visits and the empirical data gathering. The literature review consisted of reviewing the latest literature, primarily on warehousing. The purpose was to anchor the warehouse design process in theories and the current state of technology to outline the solution space of the artefact, further illustrating the link to the *framing* of DS. The external company visits were conducted with the same purpose, to gain evidence of different warehouse configurations and ask targeted questions about both reasoning behind them and identify, both pre- and post-implementation, delimitations. The empirical data was collected to then be utilized for an analysis of the current situation. One requirement directly given from this analysis was the capacity dimension, which was a prerequisite for the design process.

The design and development stage of the thesis was linked to the activities in which opportunities for improvement were identified i.e. data analysis and then the process of designing. For the latter a design process was composed which is outlined in *Section 2.7*. The resulting design was inspected from a perspective of performance.

Validation of the artefact had a clear connection to both the demonstration of the artefact and the evaluation. The first demonstration of the *proof of concept* was performed on the 25th of April where employees identified as working in or near the FGW were invited to join. The workshop lasted 60 minutes and consisted of a 30-minute presentation followed by 30 minutes of discussion. As established, this input could be used for revisiting *creating*. The evaluation of the artefact was conducted through a more extensive presentation on the 5th of June 2024 for involved stakeholders at the Alfdex facility.

2.4 Literature Review

The goal of a literature review is, according to Rowley and Slack (2004), to be informed by existing knowledge in a subject area. Furthermore, the authors mean that the goal is to create a summary on a subject field by utilizing a range of different sources such as journal articles, books and web-based resources. Additionally, literature reviews are important to build an understanding of relevant concepts and terminology as well as aid the researcher in analyzing and interpreting results.

The literature review was conducted by searching in the databases LUBSearch, Lund University's own database, and Google Scholar. The main approach was to search using relevant keywords, such as warehouse configuration, warehouse contextual factors and warehouse storage policies. A main feature was to use the "Advanced search" to filter out irrelevant articles, such as warehouse design NOT omni-channel or warehouse configuration AND literature review. The two main criteria were the number of citations, to indicate the relevance of the literature in the area, and publication date, preferably newer articles to include the latest research. Additionally, literature reviews were favored since they contain an overview of the relevant articles in the field. The resulting literature included both books as well as academic and professional journals.

2.5 Empirical Data Collection

The empirical data collection encompasses all data gathered at Alfdex and during company visits. Data falls into four categories: quantitative vs. qualitative and primary vs. secondary. Quantitative data is numerical while qualitative is not (Saunders, Lewis and Thornhill, 2007). Primary data is newly collected, while secondary is data that was originally collected for some purpose but has been reanalyzed (Saunders, Lewis and Thornhill, 2007). This thesis used and analysed all four categories. Data collection methods included observations, interviews, company visits and secondary data. The outline of this section is illustrated in *Figure 2.7*.

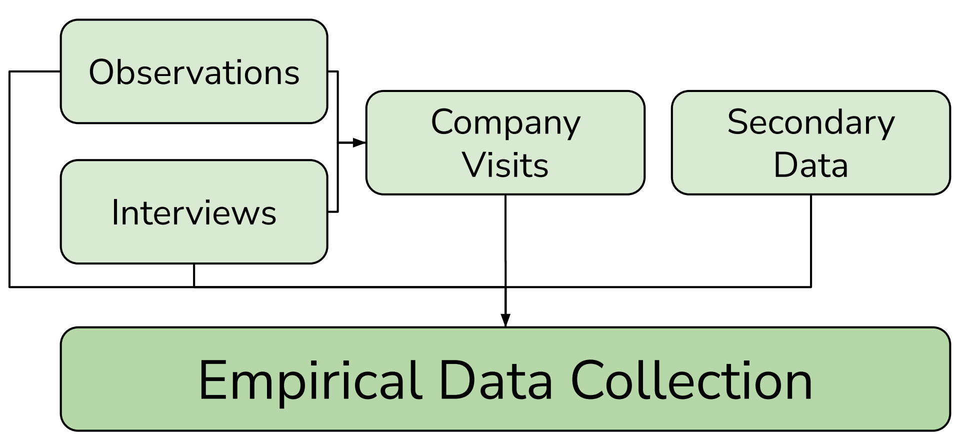

Figure 2.7: Outline of the Empirical Data Analysis Section.

2.5.1 Secondary Data

Secondary data was collected as empirical data. The definition according to Saunders, Lewis and Thornhill (2007) is data that has been collected with another intention but reanalyzed for a new purpose. This data has various forms and shapes but can be primarily classified into two categories; minimally- and non-processed data or compiled data that has been selected or summarized. There are advantages to using secondary data, the main ones being that it saves time for the researcher, which does not have to collect data from scratch, and adds context to the analysis. However, secondary data is highly dependent on the quality of its registration, which risks being subpar or biased. The secondary data in the thesis was collected from a combination of the ERP system and drawings and is presented in *Table 2.1*.

Table 2.1: Secondary data retrieved.

Type of Data	Source of Data	Date of Access	Description of Document
Map	Logistics Manager - Email	12th February 2024	Map, including dimensions
Sales for 2023	Logistics Manager - Email	12th February 2024	Sold units during 2023.
Stock transactions	Microsoft Dynamics AX	15th February 2024	Stock transactions data
Shipping Plan	Production Planner - Email	21st February 2024	Pallet shipments of 2023
Production Output	Production Planner - Email	13th March 2024	Production output from production lines per week

2.5.2 Observations

Observations are one type of empirical data collected and used in this thesis. Saunders et al. (2007) classifies observations into two main categories: participant observations and structured observations. Participant observation is when the observer takes part in the observation, often unsystematic and unstructured, while the structured observation is systematic and has a high level of predetermined structure. Denscombe (2010) claims that there are advantages and disadvantages with direct observations. The main advantage of observations is that it is primary data, the observer can see it with their own eyes. However, this is also the main drawback, since it is subject to individual perception. The perception of an observation depends on several factors; familiarity, interpretation depends on past experiences and the current state, the physical and emotional state of the researcher.

Participant observations

The participant observations in this thesis are qualitative and consist of inspecting the FGW configuration. The main purpose is to gain an understanding of the current layout and operations. To reduce the impact of observer bias both the scope and method of investigation are defined beforehand. The subject, method and accompanying descriptions of each participant observation are presented in *Table 2.2*. The first observation was a tour of the whole Alfdex facility to get an initial understanding of the company and the problem at hand. Due to the availability of the FGW, several minor observations were made during the period spent at the Alfdex facility. These were made with different purposes in mind, one being mapping the FGW. Additionally, the different operations were observed, including receiving, put-away, ”pallet flag” picking, SKU picking and staging. These operation specific observations acted as prelude to the interviews.

Table 2.2: Participant Observations at Alfdex.

Observation	Date	Purpose	Attendees
Tour of Facility	2023-10-03	Introduction to problem. Tour of the production area, RMW, FGW, shipping & offices.	Logistics Manager
Informal Observations	Weekly January 2024 - March 2024	Investigating the FGW through minor observations.	None specified
Loading & Put-Away Process	2024-03-04	Understanding the put-away & loading process.	First Shift Warehouse Worker
Pallet Flag Picking Process	2024-03-05	Understanding the pallet flag picking process.	Shipping Coordinator
Pallet Picking Process	2024-03-05	Understanding the pallet picking process.	Second Shift Warehouse Worker
Receiving	2024-03-22	Understanding the receiving process.	Production Forklift Operator

Structured observations

The structured observations in this thesis are quantitative and consisted of manual measurements in the FGW. The observations performed in relation to this are presented in *Table 2.3*. The observations included measuring distance, size of elements of physical layout, time, duration of storage and travel time, with size measurements done by hand using a yardstick to approximate distances within the warehouse This included dimensions of temporary storage, storage bins and loading area that were used in the mapping of the FGW. Additionally, the time of the different processes were measured. In contrast to qualitative data, quantitative observations serve to provide accurate data on each procedure. For this purpose it is necessitated that the quantitative data is based on a suitable number of measurements. Thus, all time measurements were done multiple times to increase accuracy. The suitable number of measurements, duration and number of days, depended on frequency of the observed phenomenon. The storage and some travel times were measured for one day, while others, such as travel from storage bin to loading area and onto trucks, were measured throughout the week to minimize noise and increase accuracy.

Table 2.3: Structured Observations, in the form of measurements, at Alfdex.

Measurement	**Date**	**Duration**	**Unit**	**Collection Method**
Dimensions of warehouse elements	2024-02-12	13:00 - 15:00	Meter	Single measurement of each distance.
Travel time Inbound → Arrival	2024-03-04	14:00 - 14:10	Seconds	5 measurements in one session.
Travel time Arrival → Storage	2024-03-04	14:10 - 14.20	Seconds	5 measurements in one session.
Travel time Storage → Loading area	2024-03-05 - 2024-03-11	Each pick wave	Seconds	Measured for all pick waves, over one week
Pallet flag picking time	2024-03-05 - 2024-03-11	Each pick wave	Minutes	Measured for all pick waves, over one week
Travel time Loading area → truck	2024-03-04	14:20 - 14:30	Seconds	5 measurements in one session.

2.5.3 Interviews

Interviews were another type of collected data for the project. According to Saunders, Lewis, and Thornhill (2007), interviews can be organized into three different classifications: structured, semi-structured, or unstructured interviews. Structured interviews are a highly standardized procedure where the interviewer reads out the questions in a neutral way to avoid bias and records the answer. These are often seen as quantitative since they yield quantifiable data. On the other hand, semi-structured and unstructured interviews are classified as qualitative. In semi-structured interviews, the researcher has a list of topics and questions but may vary by excluding, adding, or changing the order of questions based on the interviewee's position and knowledge. Lastly, unstructured interviews are informal, with interviewees free to express their ideas and observations within a predetermined subject area.

Denscombe (2010) pointed out that there are several advantages to conducting interviews. Primarily, interviews are an effective format for gaining access to the priorities of the informant, since they get to expand on their ideas, opinions and present what they regard as crucial factors. Due to the flexibility and openness of semi- and un-structured interviews, the interviewer can respond to the interviewee. Furthermore, it is a tool to gain deep and detailed insights into the organization and subject areas which generates insights for the interviewee. Additionally, they are easy to conduct since requiring minimal equipment.

There are pitfalls to be aware of when interviewing. The main drawback is the interviewer effect, where an interviewee responds differently depending on the interviewer. The effect depends on several aspects of the interviewer such as age, sex and ethnicity as well as behavior and manners. Furthermore, there is also the issue of the interviewee trying to state what they believe the interviewer wishes to hear, instead of their own experience. These effects are a direct consequence of how well the interviewer prepares and conducts the interview, in terms of selecting the interview subject, framing questions and leading the interview. Interviews are also time-consuming, taking away the resource of the interviewee from work.

Table 2.4: Interviews conducted at Alfdex.

Type	Date (Duration)	Purpose	Attendees
Semi-structured	3rd October 2023 (30 min)	Understand the scope and delimitations of thesis project	Logistics Manager
Semi-structured	16th January 2023 (120 min)	Expectaions, company visits, KPIs, WMS, interviewees	Logistics Manager
Semi-structured	14th February 2024 (60 min)	Discussed demand forecasts and requirements for FGW	Logistics Manager
Unstructured	Weekly (30-90 min) Jan - Mar 2024	Wide ranging discussions and follow-up on the project.	Logistics Manager
Structured	13th March 2024 (45 min)	Interview about their role and experienced wastefulness	Production Planner
Structured	13th March 2024 (45 min)	Interview about their role and experienced wastefulness	Shipping Coordinator
Structured	13th March 2024 (45 min)	Interview about their role and experienced wastefulness	Shipping Coordinator
Structured	14th March 2024 (30 min)	Interview about their role and experienced wastefulness	Shift Leader of Warehouse Workers
Structured	2024-03-14 (30 min)	Interview about their role and experienced wastefulness	Warehouse Worker (first shift)
Structured	14th March 2024 (30 min)	Interview about their role and experienced wastefulness	Warehouse Worker (second shift)
Structured	22nd March 2024 (40 min)	Interview about their role and experienced wastefulness	Production Forklift Operator

2.5.4 Company Visits

Three external company visits were performed to obtain insights on actual warehouse design & resources, focusing particularly on AGVs and performance. These companies provided a varied picture of FGWs. The visits displayed a attributes from *interviews* and *observations*. Each visit was initiated with a tour of the warehouse, primarily focused on gaining some initial understanding of their warehouse. Subsequently, an interview was conducted, where more in-depth questions on reasoning behind design, resources, performance measurements and automation choices could be asked. Different findings during the tour influenced what questions were asked during the interview, reminding of a semi-structured interview format. Each part of the company visits, tour and interview respectively, was planned to take 30-45 minutes. A summary of dates and interviewees can be found in *Table 2.5*.

Table 2.5: Company visits conducted in the project.

Company	Date	Role of Interviewee
Company A	2024-02-07	Operations Manager
Company B	2024-02-16	Internal Logistics Manager
Company C	2024-02-29	Warehouse Logistic Manager

2.6 Data Analysis

Data analysis was a crucial step to arrive at the proposed solution since data, especially quantitative, is not useful without processing and analysis (Saunders, Lewis and Thornhill, 2007). The data analysis was directly dependent on the data collection, since the analysis is only as good as the input data. The analysis should, in accordance with the research process, help with developing the artifact. Additionally, the frameworks and tools used to analyze the data were retrieved in the literature review. How the data analysis was connected to the data collection and the development of the artifact is illustrated in *Figure 2.8*.

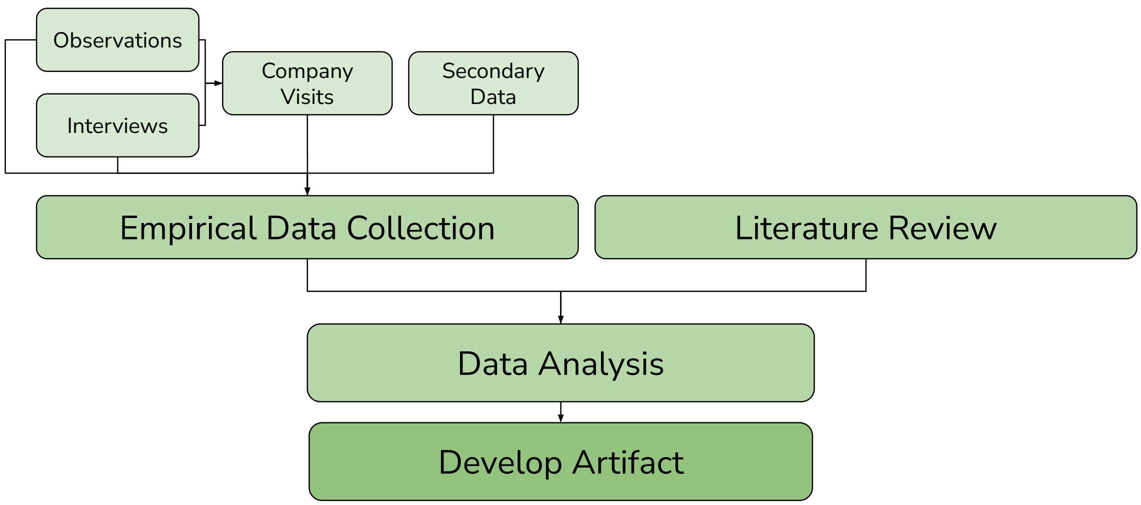

Figure 2.8: Data analysis connection to data collection and artifact.

The data analysis process, according to Denscombe (2010), should be conducted in five steps; (1) Data preparation, (2) Initial exploration of data, (3) Analysis of the data, (4) Presentation and display of the data and (5) Validation of the data. This process should be conducted separately for qualitative and quantitative data. Quantitative data can be analyzed with techniques such as charts, graphs and statistics to present and examine relationships and trends in the data (Saunders, Lewis and Thornhill, 2007). The complete process, applied to this thesis, is summarized and illustrated below in *Figure 2.9*. In the following subsections first for qualitative, and then quantitative, data analysis is discussed further following the five presented steps.

	Qualitative Data	Quantitative Data
1. Data Preparation	- Preparing interview protocols - Performing interviews, observations and company visits - Transcribing the interviews - Acquiring relevant documents	- Acquiring relevant documents - Preparing data-collection protocols - Collecting, summarizing and transferring data to Excel - Data cleaning
2. Initial Exploration of Data	- Summarizing key contextual factors for each company - Summarizing employee rankings - Looked for obvious recurrent themes or issues	- “Playing around” with the data: using sort and filter functions in Excel - Looking for obvious trends or correlations
3. Analysis of the Data	- Grouping into categories - Comparing categories - Developing company visit insights - Creating rankings for Muda Matrices	- Categorizing the data: according to relevant metrics, such as per day, customer, article number or type of SKU - Using analytical tools - Linking to research questions
4. Presentation and Display of the Data	- Writing interpretation of findings in report - Creating Muda Matrices - Presenting company visit insights - Illustrating layout of FGW	- Presenting result using tables, figures and analytical tools - Utilizing recurrent themes: such as color schemes and reuse of parts of figures - Writing explanations in report
5. Validation of the Data	- Using multiple sources; both employees and companies - Using multiple types of data: both oral and secondary data - Validating at workshop with Alfdex employees	- Utilizing multiple sources, to ensure internal consistency - Evaluating of findings in weekly meetings with Logistics Manager - Validating at workshop with Alfdex employees

Figure 2.9: The data analysis process of the thesis, adapted from Denscombe (2010).

2.6.1 Qualitative Data

The qualitative data consisted of, as reported in the separate Empirical Data Collection parts above, *participant observations, company visits and interviews.*

2.6.1.1 Data Preparation

The participant observations used data protocols in the form of empty maps of the warehouse, allowing for subsequent drawings of operations. During the observations notes were taken using a simple text editor, which required some early processing in the form of structuring and composition of notes. The data collection protocols for the company visits consisted of two parts; one focusing on the warehouse tour and a general company profiling, while the second consisted of questions targeting more specific aspects such as project implementation and AGV-considerations. The complete listing of questions, divided over the tour and the following interview, can be found in *Appendix 7.4*. The interviews were structured according to *Appendix 7.4*. The same protocol was also used for digital note-taking.

2.6.1.2 Initial Exploration of Data

The initial exploration of data for all the qualitative data types occurred during collection. For the participant observations and company visits, unexpected occurrences outside the intended phenomenon were noted down. Similarly, interviews often yielded answers not covered by the protocol, and they were, as a result, explored first. The initial exploration of company visits data involved summarizing each visit. This is presented in *Subsection 4.6.1-4.6.3*. For participant observations the exploration entailed transferring movements to digital maps drawn using Google Suite software in addition to compiling summaries of operations. These are found in *Section 4.2*. The initial exploration of interview data included compiling all problems, with descriptions and rankings, in a spreadsheet.

2.6.1.3 Analysis of the Data

Participant observations
The information gained from the participant observations did not require much analysis. As an extension of the initial exploration that consisted of looking at the operations and activities individually, the analysis consisted of putting the operations together in the correct sequence. Some initial attempts to create figures were performed using the drawn-on maps.

Company visits
The initial analysis, which commenced after all visits had been conducted, consisted of a comparison using a matrix with dimensions *company type, number of pallet positions, pallets per day, warehouse dimensions* and *truck types*. Subsequently, unique company insights were brought up, both those the interviewee believed to be of special interest during the interview and those that were particularly prominent through triangulation with literature. Those insights were developed further, utilizing the full overview of having a comparative base of four warehouses, and presented individually in text in *Analysis*.

Interviews - employee problems
The first analysis of interview data consisted of determining when problems had been mentioned more than once. This was facilitated by the problems being very tangible and although two individuals might describe the impact of a problem differently the problem was the same. One such example is two mentions of the problem of *incorrect inventory levels*, where one problem formulation was "incorrect inventory levels" while another was "missing SKUs". After grouping the same problems, simple calculations were made to determine the average ranking of each formulated problem, as well as writing a complete description.

The first phase of creating the first Muda Matrix was to determine which types of waste were relevant for the FGW. The types of waste that had been observed, and were within the scope of this thesis, were transportation, waiting, unnecessary motions, and unnecessary inventory. The Muda Matrix employed a scoring system that ranged from 1 to 7 for each waste category according to the one recommended by Joshi et al. (2015). The process of ranking the problems was performed by the authors using all prior knowledge of the warehouse operations and design. The interview notes on the question of how severe the impact and on what processes, were also a basis for the rankings. Once all the problems had been ranked their cumulative scores were calculated and the matrix sorted thereafter in descending order.

The process of the second Muda Matrix is like that of the first, however, it instead used measures relevant for the working environment. The ones that were chosen were safety and working conditions. The ranking was performed in the same way, using the interview notes as basis for if employees believed the problems could be tied to working environment. Similarly to the first, the problems were sorted after their cumulative score. The three highest scoring were highlighted for later use in the design phase.

2.6.1.4 Presentation and Display of the Data

The data from the participant observations in the form of general knowledge about operations was written as explanatory text. What routes were taken during the different operations were presented in a simple Spaghetti Diagram, see *Figure 4.9*. In terms of the company visits, the comparison between companies which utilized a matrix as described was presented in the form of a table. The summary of each company visit followed. In the succeeding chapter with analysis all *Insights* were presented in text and summarized in a table. For the interviews, the problems were presented together with their ranking and number of mentions in the form of a table. The following table was the description for every problem in the form of text. In the *Analysis* chapter the fully developed Muda Matrices were presented in table-format. The three most prominent problems in each matrix were highlighted.

2.6.1.5 Validation of the Data

The validation was conducted in several steps. Firstly, several sources were used, when possible. In terms of participant observations, dialogues have been held with employees throughout the project, discussing operations. The interviews can be said to validate the participant observations. For the Muda Matrices, see *Tables 5.1 & 5.2*, some of the problems were stated by several employees, which strengthens the credibility. This also holds for claims on operations during a company visit, which could be independently checked in dialogue during another visit. The main validation of data occurred during the workshop at Alfdex. There, a summary of all operations as perceived during participant observations and described during interviews was laid out. All tables and figures were presented for employees so that they may bring up differing opinions or hesitations. No considerations were brought up with the data that changed the performed analysis. Moreover, data has been validated throughout the thesis during weekly meetings with the company supervisor.

2.6.2 Quantitative Data

The quantitative data consists of, as reported above, *structured observations, secondary data from the ERP system and secondary data from various spreadsheets.*

2.6.2.1 Data Preparation

Data was retrieved utilizing several sources, mainly the ERP system, emails of excel-sheets from relevant personnel and own measurements. The secondary data is presented in *Table 2.1* and the measurements in *Table 2.3.* In terms of measurement period the logistics manager expressed that the fall of 2023, more specifically 4th of September to 15th of December, was a representative period for operations and stock levels. Hence that period was used.

Secondary data - ERP system
Data from the ERP system data was easily retrieved, but only gave the current stock levels in number of separators and all historical transactions in and out of the FGW. Additionally, it could only be retrieved for one article number at a time. Thus, the historical stock levels had to be backtracked, starting from the current stock level and adjusting for transactions. This was a cumbersome process, as the separators had to be converted into SKUs, which is the analyzed unit. When doing this, there were several instances of non-integer numbers, which is not possible for SKUs, due to faulty input in the ERP system. These changes often canceled out, a faulty input was corrected a week later, which had to be manually adjusted by the authors to get correct stock levels over the whole period. This process was repeated for the 13 articles with the most demand, constituting 81.8% of sales.

Secondary data - Spreadsheets
A significant part of the data was from spreadsheets provided by the Alfdex Logistics Manager and Production Planner, including sales of SKUs for 2023, production output from production lines and data of historical shipments. The data preparation in these instances corresponded to data cleaning. The main issue was the non-overlapping use of article numbers. In the ERP system, and in the files from the Production Planners, the article numbers were on a detailed level. Some articles had several variants, for example number of units per SKU or packaging material, which are distinctly different articles. The data from the Logistics Manager only contained higher level articles, as well as not all the lower volume articles, which resulted in fewer articles overall. Thus, there had to be some manual corrections, mainly grouping of article numbers, to make the data comparable.

Structured observations - Measurements
For taking measurements preparation was key. The first step was understanding the processes to measure, which comes from the participant observations. Finding relevant actors who were willing and able to set aside their ordinary routine to participate in measuring for an unspecified time was necessary. Additionally, measuring the whereabouts during picking required a very detailed grid-like representation of the warehouse where distinct movements could be logged. Simultaneously, someone had to record the number of SKUs moved. After measuring the data was put into Excel files, which enabled structured analysis.

2.6.2.2 Initial Exploration of Data

The initial exploration of data was similar for all types of quantitative data. The main activity constituting this step was to ”play around” with the data. That meant freely analyzing it using sorting and filters in Excel, as the data was consolidated into several Excel-files. This step provided an overview and initial impression of the data content.

2.6.2.3 Analysis of the Data

The data was analyzed thoroughly, for example by classifying the data according to relevant metrics, such as per day, customer, article number or type of SKU. The analysis used employed the analytical tools, which are presented in *Section 3.4*. Thus, the analysis of data was directly related to the research objectives, as RO2 investigates the current state of the FGW. The analytical tools were the analysis, in the case of the ABC-analyses, as the analysis was given by the tool. In the other instances, for example the VSM, the data analysis was to calculate and combine data, to be used in the next step of visualization.

ERP system - Stock levels
The prepared data from the ERP system on stock levels for each of the 13 biggest articles, during the measurement period, was put in the same spreadsheet. Knowing that they constitute 81.8% of sales, the total could be balanced by adding the last 18.2% of unknown SKUs. This required the assumption that stock levels are nonseasonal and rather constant throughout the year, which the Logistics Manager confirmed. The data then consisted of a list where each date had a stock level. By subsequently adding the actual weekday of every entry in a separate column allowed for analysis between weekdays. The same was done for months. By adding the distribution of SKU-types to each day's stock made analysis of internal distribution possible.

Spreadsheets - Shipment data
Clean shipment data came in the form of spreadsheets, with articles and respective quantity for each shipment day. All spreadsheets were combined into one. This one had the appearance of a list of transactions, with the date of the shipment as an entry into one column. The data was analyzed, and summarized, using Pivot-tables in Excel. Summarizing over a shipment date gave the number of SKUs in the loading area on that specific day. The distribution of SKU-types was also calculated from the total and kept. All of this allowed for further analysis such as between weekdays and between SKU-types or even SKUs.

Structured Observations - Measurements
The measurement data was analysed in Excel. The main analysis was to aggregate the data to be able to analyze it properly. For all the measurements the first analysis was to investigate the representativeness of the sample data. This was researched by comparing the total number of SKUs in the operation compared to the average number of SKUs for a typical day. Compensating for the difference gave representative operations times for an average day. The main numbers attained were average numbers, often expressed as time per SKU or time per day. Furthermore, the share of time within an operation was investigated, for example the division between value-adding and non-value-adding.

2.6.2.4 Presentation and Display of the Data

This step was crucial for this thesis, as *Chapters 4 & 5*, are built on presenting the data analysis. These sections essentially constitute RO2, investigating the current state of the FGW. Thus, the visualization of the analyses conducted is crucial to make the analyses easily understandable for the reader. These include all the analytical tools, see *Section 3.4*. A main feature of clearly explaining the figures. This includes both the figures themselves, with the use of labels and legends, as well as thoroughly explaining each presented figure. Another aspect is the use of reoccurring themes, such as building on the same figure and using the same color scheme. All analyses illustrating some part of the layout, such as the Spaghetti Diagram and the Heat Maps, see *Figure 5.7, 5.9 and 5.10*, are based on the originally presented layout of *Figure 4.10.* The color scheme remained the same in several figures, to represent a certain aspect. This is exemplified by using a dedicated color for a specific customer which is first presented in Sales per Customer in *Figure 4.7*, and then reused in Sales per Article in *Figure 4.8* and SKUs in loading are per Weekday in *Figure 5.1.* There is however a clear trade off with dedicating a color to represent a specific trait, as doing multiple analyses will make the color scheme through the thesis incoherent. To conclude, the presentation and display of the data has been crucial to communicate the data to different stakeholders, which will be described further in the next paragraph.

2.6.2.5 Validation of the Data

For the quantitative data numerous sources were used when possible. In the cases when estimations had to be made, for example for the frequency of SKUs arriving at the FGW which there was no data on, several employees were asked for a reasonable estimation. Furthermore, the data was validated by the employees. Just like for the qualitative data, the quantitative data was presented to the Logistics Manager in the weekly meeting, see *Table 2.4*, to make sure that the findings were reasonable. In some instances there were mistakes made in the data analysis, which were pointed out. None addressed the analysis itself but instead the assumptions made on SKU-type and stock held in another facility. A more extensive and planned validation also occurred at the workshop, see *Section 2.3*, where the presented data and analysis was deemed to be accurate and appropriate.

2.7 Design Process

The Design Process framework, illustrated in *Figure 2.10*, was created to address the order in which propositions for design were developed, from this point on referred to as *design propositions*. The framework illustrated on a more detailed level the "design solution" step in the research process, as illustrated in *Figure 2.6*. The design proposition steps, and the resulting new configuration, are from the contingency approach for warehouse configuration, which is further described in *Section 3.1*. The framework portrays that the order of aspects to focus on was capacity, AGVs and automation level, storage and stacking policy, storage and handling equipment. Although the process of composing the *design propositions* occured with a top-to-bottom approach according to the outline, it is also noteworthy that the process, just as mentioned in the *Design and Science Framework*, was iterative. The act of conceiving the *design propositions* does furthermore encompass the steps of *framing, creating* and *validating*, hence proving the connection the framework and observing internal iterations.

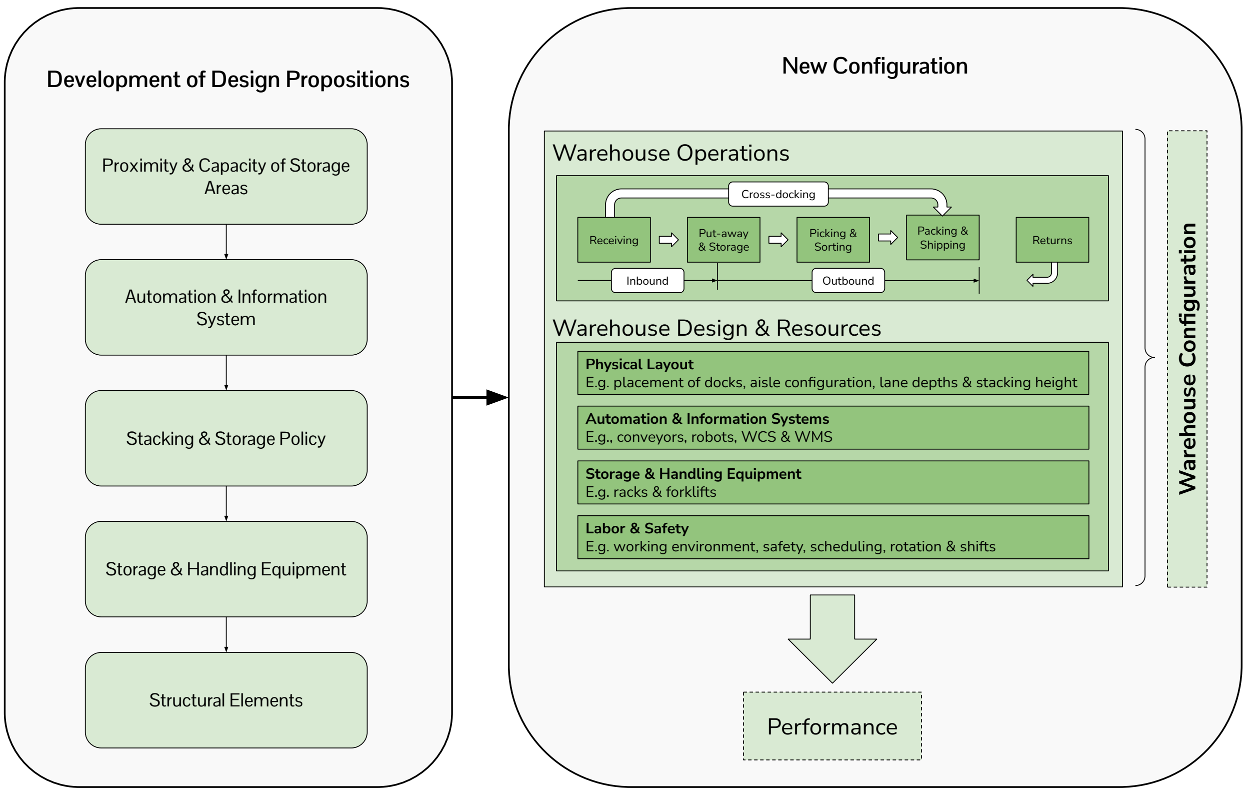

Figure 2.10: Design Process framework for order of deciding on configuration aspects.

The *design propositions* were devised through the lenses of the CAMO-approach. The CAMO-approach was remarkably applicable as it captured all aspects of the contingency framework, see *Section 3.1*, that was used throughout the thesis. The **C**ontext relates directly to contextual factors, **A**gency to the agent or to the operation, **M**echanism to the operation or design/resource that gives it and finally **O**utcome to the resulting performance. The aggregate of propositions constituted the new configuration.

2.8 Research Quality

The quality of the research primarily depends on two aspects; validity; if the research is logically valid, and reliability; if the research is correct (Näslund et al., 2010). According to Gibbert et al. (2008) these two aspects can be further elaborated into four different categories; (1) Internal validity, (2) Construct validity, (3) External validity and (4) Reliability. These four concepts are explained and summarized in *Table 2.6.* The data collection was done using triangulation, utilizing multiple methods and sources, to gain a deep and wide understanding of both the subject and task at hand (Näslund et al., 2010).

Table 2.6: Validity and reliability framework by Gibbert, Ruigrok, and Wicki (2008).

Concept	**Definition**	**Phase of Project**	**Measures to Increase Quality**
Internal validity	Refers to the causal relationships between variables and outcomes.	Data analysis	*Clear research framework*: which demonstrates that outcome y depends on variable x. *Pattern matching*: compare empirical findings with earlier predictions or patterns from different studies or settings. *Theory triangulation*: verify findings by using several perspectives.
Construct validity	The extent to which a study investigates what it claims to investigate, i.e. leads to an accurate observation of reality.	Data collection	*Establish a clear chain of evidence*: allows the reader to reconstruct how the researcher went from research questions to the final conclusions. *Triangulation*: use multiple data collection strategies and data sources to look at the problem from different angles.
External validity	The "generalizability", the extent to which the findings are applicable to other settings, of the study.	Research design	*Cross-case analysis*: study the phenomenon in multiple settings.
Reliability	The absence of random error, the same conclusions should be reached if the study is replicated.	Data collection	*Transparency*: Documentation and clarification of research procedures. *Replication*: Documentation of the data and documents used in the project, that could be reinvestigated by others later.

The perspective of how to attain high-level research quality has a clear link with the performed thesis activities. These activities and their purpose in relation to the research strategy are outlined in the form of the *research process*. The research process, complemented with the research quality perspective, is illustrated in *Figure 2.11.*

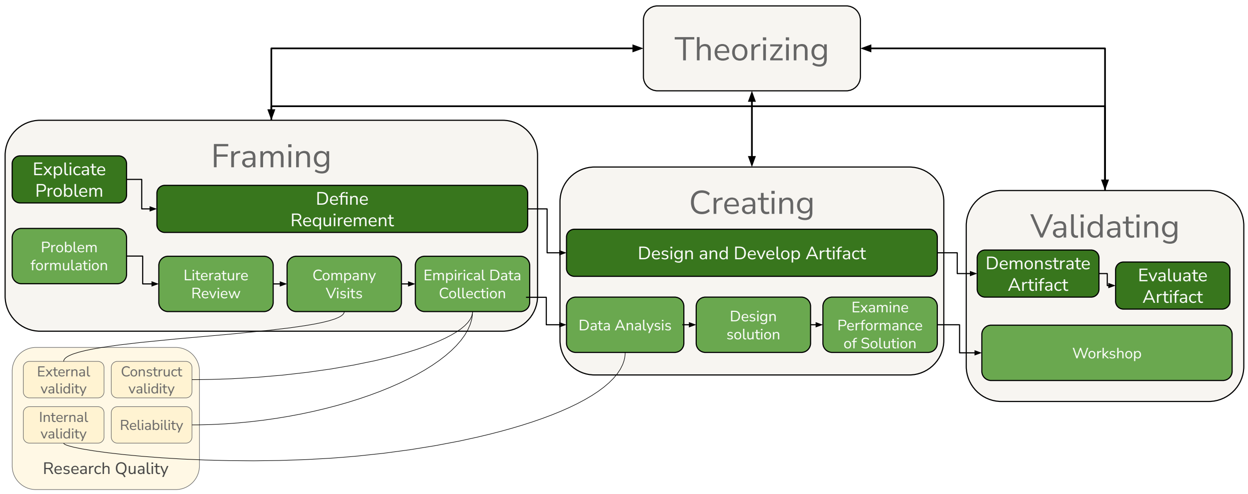

Figure 2.11: Connection between research process framework and research quality.

2.9 Methodological Framework

The methodological framework is the combination of all the activities presented in the second chapter of this thesis. The methodological framework ensured that the thesis had a clear plan and structure of how the project should be conducted. The framework related the methodological chapter with the introduction chapter. This ensured that the methodological chapter was in line with the purpose, research objectives and deliverables of the thesis. The complete methodological framework for the thesis was presented in *Figure 2.12*.

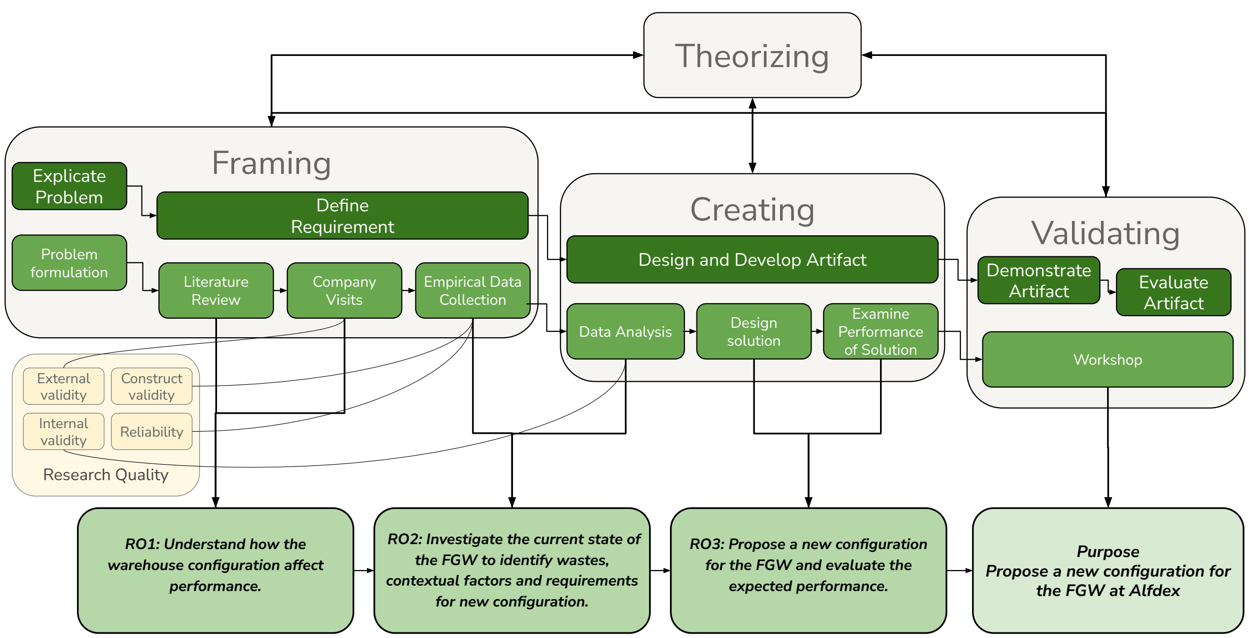

Figure 2.12: Methodological Framework.

3 FRAME OF REFERENCE

This section of the report presents the theoretical background and frameworks used to reach the research objectives. Initially, the warehouse contingency framework for a warehouse configuration is presented. As part of that framework contextual factors and performance of warehouses are accounted for. The framework also encompasses warehouse operations as well as warehouse design & resources, which are then presented. Subsequently, analytical tools are presented. Lastly, the frame of reference section is summarized into an analytical framework. The section follows the structure; Contingency Approach, Warehouse Operations, Warehouse Design & Resources, Analytical Tools and lastly Analytical Framework.

3.1 Contingency Approach

In this section of the report the contingency approach to warehouse configuration is presented. The section is divided into three subsections: (i) the conceptual contingency framework for the warehouse configuration, (ii) contextual factors in a warehouse configuration and (iii) performance in a warehousing setting and a discussion on appropriate KPIs.

3.1.1 Conceptual Framework for Warehouse Configuration

According to the contingency approach, organizations should match structures and processes to their internal and external environments to improve their ability to perform. It is also important to reach a successful configuration (Kembro and Norrman, 2021). This is expressed in the contingency theory, which claims that to react to changing contextual factors organization should adapt their internal structure (Lawrence and Lorsch, 1967). It is central for an organization to match the structural characteristics of the company with their corresponding environment (Donaldson, 2001). It has been observed that companies using a contingency approach in a warehousing context perform better (Faber et al., 2018). Thus, a conceptual contingency framework for warehouse configuration by Kembro and Norrman (2021) will be used in the report, see *Figure 3.1.* To conclude, contextual factors should significantly influence the warehouse configuration.

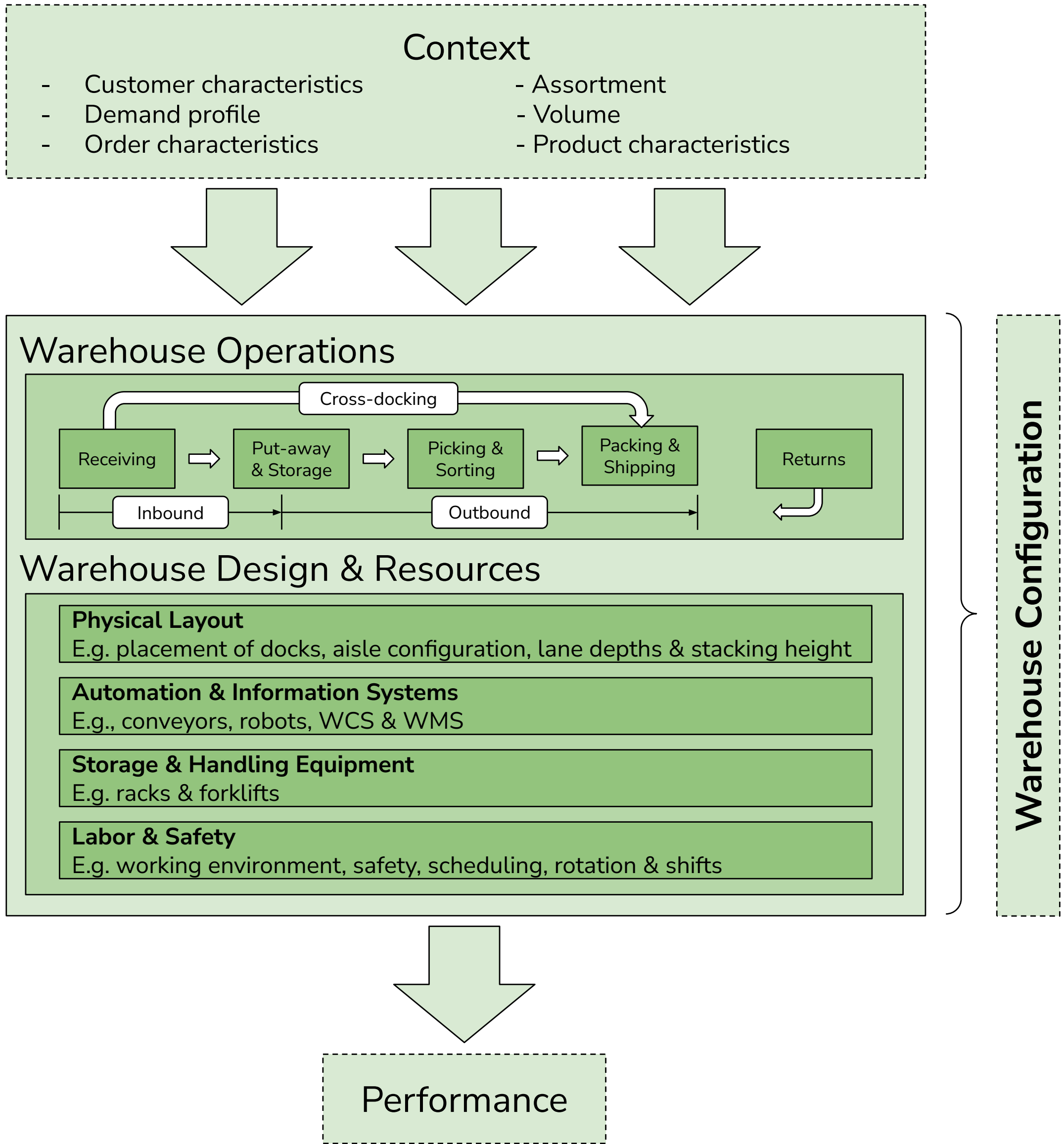

Figure 3.1: Conceptual contingency framework for a warehouse configuration by Kembro and Norrman (2021).

The configuration of a warehouse consists of the combination of operations, design aspects, and resources in a warehouse according to Kembro and Norrman (2021). The term operations are used for activities or processes that occur in a warehouse, such as receiving, put-away, storage, picking, sorting, packing, and shipping as well as returns. Design & resources describes the physical infrastructure and the tools in the warehouse that enables the warehouse operations. These include physical layout of the warehouse, automation and information systems, storage and handling equipment, as well as labor and safety. To achieve a successful warehouse configuration both the operations and the design & resources must be considered and should be influenced by contextual factors.

3.1.2 Contextual factors

Contextual factors are crucial according to the contingency approach for making correct decisions when designing a new warehouse configuration. Faber et al. (2018) claims that contextual factors can be principally divided into two categories: complexity and uncertainty. Where complexity refers to factors within the company and uncertainty to factors outside the domain of the company. Additionally, there are factors that are influenced by both internal and external factors. Another important aspect to note is the interrelatedness of the factors, some factors influence each other, and a change of some parts will change the context for other (Kembro and Norrman, 2021). This fact stresses the importance of combining a holistic perspective with an iterative approach when designing a new warehouse configuration.

The importance of factors varies in different contexts. The most important aspect is the purpose of the warehouse, which can range from production to retail, service parts, or 3PL distribution warehouses (Rouwenhorst et al., 1999; Bartholdi and Hackman, 2019). Additionally, it is affected by other aspects of the company such as industry, country and type of product. Some of the contextual factors, such as sector or product characteristics, affect all operations, while others are more directly linked to individual processes (Kembro and Norrman, 2021). A table of different contextual factors relevant to this thesis is presented in *Table 3.1.* To conclude, the different contextual factors have different influences in different contexts, but they are always important to consider when designing a new warehouse configuration.

Table 3.1: Contextual factors, including description and influences, based on Kembro and Norrman (2021), Faber et al. (2018) and Rouwenhorst et al. (1999).

Contextual Factor	Description	Influence
Product characteristics	The characteristics of the SKU, such as dimension, stackability, and weight.	Order and handling equipment
Order characteristics	The characteristics of the order, for example number of orders and picks per order	Picking process
Type of warehouse	Such as production or distribution	Types of operations
Demand characteristics	Amount, volatility, trend and seasonality.	Storage and labor requirement

3.1.3 Performance

The performance of warehouses increases when contextual factors are considered. Decisions related to logistics, based on performance and preconditions, have gained more strategic importance (Rafele, 2004). However, not all companies have kept up with the new ways to measure performance while global markets become increasingly competitive and complex. Companies with distinctly different contextual factors must now compete (Kaplan & Norton, 2006). Research conducted by Faber et al. (2018) supports the significance of clear procedures for taking measurements. Their findings indicate that warehouses of companies that consider contextual factors perform better, stressing the need for companies to evaluate their procedures. To measure performance many companies employ *KPIs*.

KPIs - Key Performance Indicators are described by Parmenter (2017) as the set of measures that observe the aspects of performance most critical to a company's success and are meant to lead to action. The concept of leading and lagging indicators are central in understanding what constitutes a valuable KPI. While on one hand other performance measurements can be lagging in that they evaluate historic performance, KPIs are naturally current or future oriented. Parmenter claims there are seven characteristics of KPIs that offer insights into creating metrics that are specific, measurable, achievable, relevant, and time-bound, fostering a robust framework for strategic performance evaluation. The characteristics are *non-financial, measured frequently, directly used for decision-making, can be affected by some understood action, ties to some activity or part of the organization, has a significant on impact critical success factors, and positively impacts other performance measures.*

A.F. Costa et al., (2023) establish that in a warehousing context the KPIs are usually related to stock-keeping and storage. They also press on the matter that all KPIs must have "owners", someone directly responsible for acting on changes. As mentioned in warehousing operations, the five main areas in warehousing that most operations belong to are *Receiving, Put-away, Storage, Order-picking* and *Shipping*. Good examples of KPIs for each warehouse segment with regards to *productivity, utilization* and *quality* are presented in *Table 3.2*. An example of a poor KPI for a warehouse could be the very nondescript *working hours of employees.*

Table 3.2: Matrix with potentially good KPIs for a warehouse.

Process	Productivity	Utilization	Quality
Receiving	Units received per hour	Dock door utilization	Accuracy of received items
Put-away	Pallets put away per shift	Storage rack space usage	Accuracy of put-away
Storage	Retrieval time per item	Warehouse capacity usage	Inventory accuracy
Order-picking	Orders picked per hour	Pick face utilization	Picking accuracy
Shipping	Orders shipped per day	Loading dock utilization	On-time shipments

3.2 Warehouse Operations

Warehouse operations are described as the activities or processes that occur in a warehouse, such as receiving, put-away, storage, picking, sorting, packing, and shipping as well as returns (Kembro and Norrman, 2021). The process is illustrated in *Figure 3.2*. According to Bartholdi and Hackman (2019) the receiving depends on the arrival process and once arrived is often staged before put-away. The put-away process is essential as a suitable storage location will affect the efficiency of picking. For put-away and picking the WMS plays a crucial role. In terms of a warehouse's operation expenses the picking process generally makes up 55%. Order picking typically consists of travelling (55%), searching (15%), extracting (10%) as well as paperwork and other activities (10%) (Bartholdi and Hackman, 2019). After picking comes shipping. This generally means consolidation into a single shipment, to facilitate this and minimize loading time many warehouses also stage products. Due to the scope and delimitations of this thesis, see *Section 1.5*, the put-away & storage, picking & sorting, and shipping will be thoroughly examined in the following subsections.

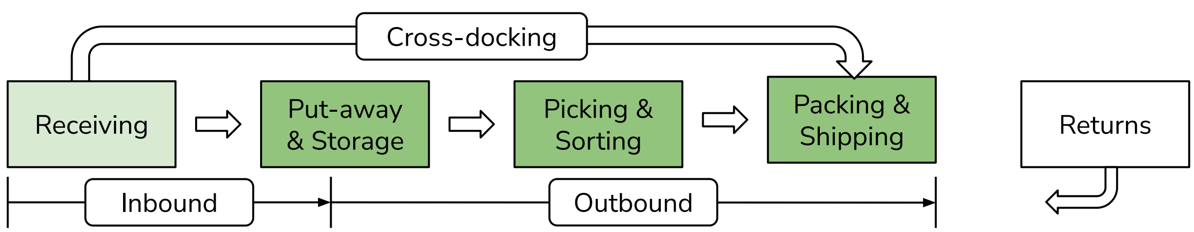

Figure 3.2: Warehouse operations activities (Kembro and Norrman, 2021).

The warehouse operations can be improved, according to Bartholdi and Hackman (2019), by following the following two rules. Operations should as a rule strive to *create an as continuous flow as possible* for the products. This is done by minimizing double handling, the act of picking something up that has already been put down. The accumulation of double handling in a warehouse sums up to a considerable cost. Another rule to strive for is to *scan the product at all key decision points* to increase the visibility of the stock.

3.2.1 Put-away & Storage

The put-away process is essential as the storage location will affect the efficiency of, both in terms of time and costs, how it is later picked according to Bartholdi and Hackman (2019). An important element is to know the current status of the warehouse. Thus, according to the authors, it is required to keep a "second inventory" for all stock locations, in terms of size, allowed weight and availability. Additionally, it is common to scan the SKUs when they have been placed at a stock location, to manage the second inventory. The key is to know where to put the received SKU, the warehouse must have a storage policy outlining where the product should be placed. There are several different storage policies, summarized in *Table 3.3*. Due to the importance and impact of storage policies on the put-away and storage process, the policies are discussed in the following sections.

Table 3.3: Summary of storage policies (Bartholdi and Hackman, 2019; Gu et al., 2007; Thomas and Meller, 2014; de Koster et al., 2007).

Type	Description	Advantages	Disadvantages
Dedicated Storage	•Each location is dedicated to a single product •Suitable for popular products	+ Efficient picking of popular SKUS + The employees knows where the different products are stored	- Ineffective utilization, an empty location is unavailable before the restocking.
Shared Storage	•Each location can be used for each product.	+ Increased utilization + Increased flexibility	- Reliant on the WMS - Employees do not know where the products are stored - A more time-consuming put-away process, since products must be taken to different locations - Increased complexity due to trade-offs
Class Based Storage	•Groups items into classes based on activity level, items are placed randomly within the class •Suitable when demand is skewed, or Pareto-distributed	+ Reduced travel + Efficient picking of popular SKUS	- Locations are random - Employees does not know where the products are stored
Full-Turnover Storage	•Items are ranked and placed after their sales numbers, fast moving items in the superior locations	+ Reduced travel + Efficient picking of popular SKUS	- Time limited solution, the ranking varies with changes in demand and product assortment - Information intensive, requires analysis of reliable order and sales data to update the ranking - Requires labor when the ranking is updated - Employees does not know where the products are stored
Family Grouping	•Items that are picked together are placed together •Suitable for products with highly correlated demand	+ Effective picking of combination that are picked together	- Time limited solution, the families varies with changes in demand and product assortment - Information intensive, requires analysis of reliable order and sales data to update the families - Requires labor when the ranking is updated

The two main policies for storing products are dedicated and shared storage (Bartholdi and Hackman, 2019). Dedicated storage is when each location is dedicated to a single product. The main advantage of the policy is its innate simplicity. Since products are stored in the same location regardless, an advanced information system is not necessary. In practicality workers can learn where products are stored (de Koster et al., 2007). However, there are drawbacks to the approach. The main disadvantage is the low utilization, estimated to 50% (Bartholdi and Hackman, 2019). Since the locations are generally dimensioned for the maximum inventory of the product, which is rare, it is not effectively utilized (Bartholdi and Hackman, 2019; de Koster et al., 2007). The shared storage policy, also called random storage, is where any product can be placed in any storage location. The main advantage is the increase in utilization, or resulting lower space requirement, as each location can be used. However, it is heavily reliant on the information system and put-away is more time-consuming due to the complexity of different locations (Bartholdi and Hackman, 2019).

There are also storage policies that depend on demand characteristics; class-based, full-turnover and family grouping storage. In class-based storage products are grouped into classes by some measure of the demand frequency, such as pick volume, and stored randomly within (de Koster et al., 2007). The products are often classified with an ABC-classification, where A is the class with the most products. It has been shown that a smaller number of classes, less than five, are preferable (Guo et al., 2016). The classification within the warehouse can be made in three main ways, (i) diagonal., (ii) across-aisle and (iii) within-aisle, which is illustrated in *Figure 3.3*. Another variant is the full-turnover policy, where each product is ranked and stored after its individual sales data (de Koster et al., 2007). Lastly, using a family grouping storage SKUs that are picked together are also stored together (de Koster et al., 2007). The main advantage of these policies is that the most popular SKUs are efficiently picked (Yu et al., 2022; Rao and Adil, 2017; de Koster et al., 2007).

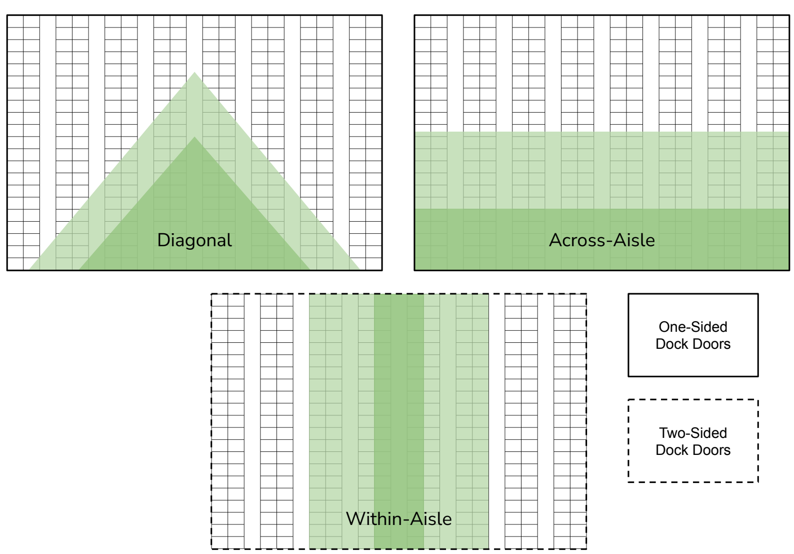

Figure 3.3: Variations of the Class-Cased Storage Policy, Adapted from Thomas and Meller (2014).

The optimal policy, or combination of policies, are not clear-cut. It is common to in practice combine different policies, for example shared and dedicated storage, to get the benefits of both high utilization and fast picks (Bartholdi and Hackman, 2019). Some different policies are similar and can be hard to distinguish. For example, the dedicated-, full turnover- and shared storage-policy can be described as different versions of the class-based storage, but with differently sized classes (Gu et al., 2007). This has had an impact on literature, where results vary between studies (Guo et al., 2016). However, the authors claim that in one specific setting, class-based storage has been seen to outperform the full-turnover and random storage policies. The authors further state that this is due to the fact that full-turnover needs more storage space but has a shorter traveling distance on average. Thus, each has advantages and disadvantages and should be investigated in the specific contextual setting.

3.2.2 Picking

Order picking is the process of retrieving products from storage in response to a specific customer request (de Koster et al., 2007). The picking process can be done in sequence, one picker at a time which is cost efficient, or in parallel, several pickers simultaneously which is faster (Gu et al., 2007). Before the picking occurs, the company must verify that they have the inventory on hand (Bartholdi and Hackman, 2019). Then a pick list must be made, that guides the order-picking. The pick list can consist of both order lines and pick-lines. Where order lines that contains information about the requested item and of the quantity in an order. On the other hand pick-lines, or picks, are instructions about where and what the order-pickers should pick and in what quantity for individual items (Bartholdi and Hackman, 2019). The order picking process is reliant on the WMS, to coordinate the picking.

Order-picking is an expensive part of the warehouse processes. Estimates often contribute most of the warehouse operations expenses to picking, ranging from 55% to 65% (Bartholdi and Hackman, 2019; Petersen, 1997). The order picking process is further estimated to be divided between travelling (55%), searching (15%), extracting (10%) as well as paper-work and other activities (10%) (Bartholdi and Hackman, 2019). The process is the most labor-intensive operation in warehouses with manual systems, and a very capital-intensive operation in warehouses with automated systems (de Koster et al., 2007). The authors further mention that due to the process being expensive, order picking has become a high priority area for warehouse professionals.

The order picking method consists of some, or all, of the following steps: batching, routing and sequencing, and sorting (Gu et al., 2007). Batching is the process of picking the article for multiple orders at once, the opposite of discrete picking that only deals with one pick at a time (de Koster et al., 2007). When picking multiple items at the same time, the items must be sorted. There are several variants of sorting combined with batching, such as batching with sort-after-pick (Gu et al., 2007). The picking methods can further be differentiated by geography, zoning, and time, wave-picking. Where zoning describes separating the warehouse into different sections, enabling fast parallel picking (Gu et al., 2007). Wave-picking is batching orders to be dealt with in a picking wave (de Koster et al., 2007).

3.2.3 Shipping

The final process of the warehouse operations is the shipping. The shipping process is the interface for the outgoing material flow (Gu et al., 2007). The order and shipping process is crucial to maintain a high service level since the faster an order can be retrieved, the sooner it is available for shipping to the customer (de Koster et al., 2007). It is common to have a dedicated shipping area, where the orders are checked and packed, before being shipped to the customer (Rouwenhorst et al., 1999).

3.3 Warehouse Design & Resources

The other part constituting the warehouse configuration is the design & resources. This consists of the physical layout, automation and information system, storage & handling equipment as well as labor & safety. These parts are covered in this section.

3.3.1 Physical Layout

The physical layout of a warehouse depends on several factors. The layout constitutes several parts such as the storage of pallets, aisle configuration, lane depth and location of receiving and shipping. Additionally, the layout depends on the type of warehouse. In this thesis the warehouse only stores unit-load SKUs. Thus, the layout investigated is for unit-load warehouses, since only a single unit of material is handled.

3.3.1.1 Storage of SKUs

A main feature of the physical layout is to determine how the SKUs are to be stored. The primary decision is if the pallets should be placed on the floor, often stacked, or placed into racks. According to Bartholdi and Hackman (2019) stacking is preferable, if using floor storage, since it increases the number of pallets per unit of floor storage. However, this depends on the "stackability" of the pallets, which is the ability of the pallets to be stacked. For pallets to be stackable they should have an even top and bottom surface as well as not being fragile or too heavy. Although stacking pallets can be useful in some cases, there are several advantages of using racks instead. These benefits are presented in the list below. However, switching from stacking pallet to racks will cost. This cost is both the price of the racks as well as the implementation cost of new operations. Thus, a decision can be reached by investigating if the expected savings exceed the cost of the transition. Of the items listed below, the first two can be quantified in monetary terms, while the third cannot. To conclude, there is a tradeoff to be made using both qualitative and quantitative measures to decide if it is preferable to transition from floor storage to racks.

- *Increased number of pallets*: by utilizing the height of the building more pallets can be stored per unit of floor storage which increases the capacity. This of course depends on the stackability of the pallets, space dedicated to the racks and height of the building.

- *Potential reduction in labor*: by making products easier to store or retrieve. The stacked pallets can be harder to retrieve due to unevenness. This could increase the throughput or decrease the labor requirements.

- *Safer work environment and decreased damage to products*: due to the accidents that are more easily occurred due to the stacking.

3.3.1.2 Lane depth

Another aspect of the physical layout is the lane depth. According to Bartholdi and Hackman (2019) the main reason to store pallets in lanes is to minimize the space dedicated to aisles. Aisles is not directly revenue-generating, since its space is used for storage, but is necessary to access the storage locations. By using lanes, the percentage of warehouse area dedicated to aisles is decreasing, since several storage locations share the same aisle. The main decision is the depth, how many pallets are stored between the aisles, of each lane. Here is a clear trade-off between space utilization and accessibility. A double-deep layout fits approximately 41% more pallets than a single-deep layout in the same area. However, when using multiple-deep lanes only the latest placed pallet is immediately accessible. For deeper lanes there is also the risk of *honeycombing*. This occurs when a multiple-deep lane is dedicated to a single SKU to avoid double handling. When a three pallets deep lane is only filled with one pallet, the other two pallet locations are empty but unavailable, thus the utilization is at this point only 33% for the lane. To conclude, there is a clear trade-off between accessibility and space utilization when deciding the lane depth.

3.3.1.3 Location of Receiving and Shipping

An important aspect to consider when designing the physical layout is the location of receiving and shipping. According to Bartholdi and Hackman (2019) there are two main configurations: flow-through and U-flow. The flow through configuration has the receiving and shipping in the middle on opposite sides of the warehouse, such that products will "flow through", see *Figure 3.4*. In this case, the best locations are in the straight line between the receiving and shipping, decreasingly convenient towards the edges. This is the optimal location, given the aisle configuration. If the receiving and shipping were to be shifted to the right the most convenient locations would still be in the straight line between them, while the locations to the left would be more inconvenient. Thus, this would generate a worse configuration. Another configuration is the U-flow configuration, where receiving and shipping are in the same approximate place, see *Figure 3.4*. With this configuration, the best locations are within the absolute shortest distance from the receiving and shipping location.

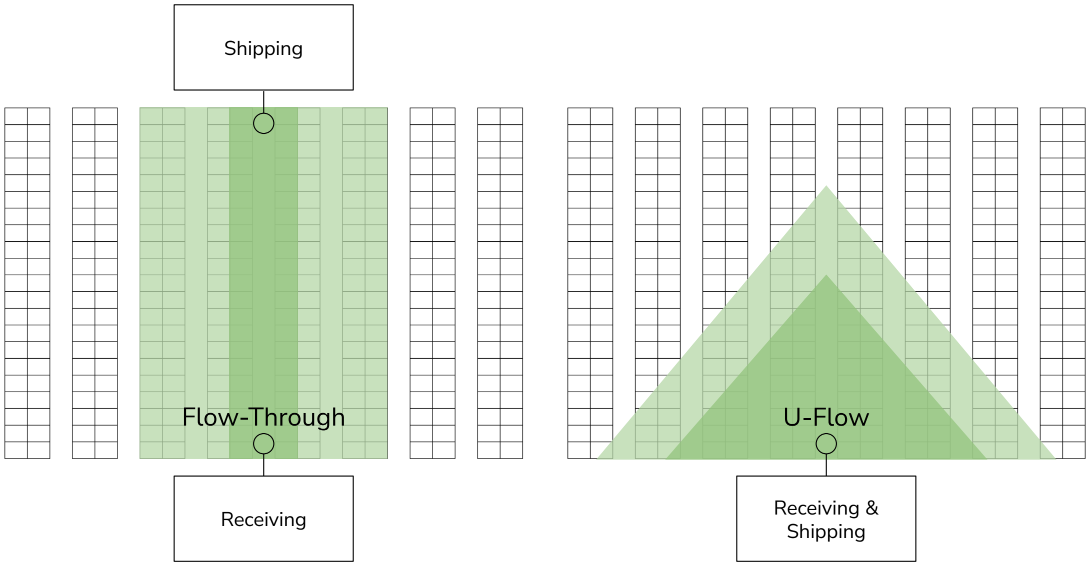

Figure 3.4: Flow-through, left, and U-flow, right, configuration. Adapted from Bartholdi and Hackman (2019).

According to Bartholdi and Hackman (2019) and Huertas et al. (2007) there are some advantages and disadvantages of each configuration. These are listed below.

Flow-through configuration:

- Less risk of interference, since all products flow in the same direction.
- Many reasonably convenient locations.
- Few very convenient locations.
- More appropriate for high volume warehouses.
- Suitable for buildings that are long and narrow.
- Reduces the efficiency that might be gained of using dual cycle transactions.

U-flow configuration:

- The most convenient locations are very convenient.
- The least convenient locations are very inconvenient.
- Suitable when products are Pareto-distributed (ABC-classified).
- Reduction in dead-hanging: put-away can more easily be combined with a retrieval since they have the same starting position.
- Minimizes area dedicated to apron, the place where forklifts are stored.
- Easier to expand the warehouse in the three other directions.

3.3.1.4 Aisle Configuration

Another part of the physical layout is the aisle configuration. According to Gue and Meller (2008) warehouses typically consist of single or double-deep pallet racks that are arranged in parallel picking aisles. The typical aisle configuration is due to two unwritten rules in warehouse design; (i) picking aisles must be straight and parallel to each other and (ii) if present, cross aisles must be straight, and they must meet they must meet picking aisles at right angles. However, aisles could in practice be structured in many ways.

3.3.2 Storage & Handling Equipment

Storage & handling equipment are essential tools to create an efficient warehouse. By utilizing the equipment several improvements can be made. Thus, the following two sections will dig deeper into how and why storage & handling equipment can be used in the warehouse configuration.

3.3.2.1 Storage equipment

There are several advantages to using storage equipment. According to Bartholdi and Hackman (2019) some advantages of storage equipment are: (i) increased picking efficiency, since the goods are accessible and in a convenient location and height, (ii) categorization of similar SKUs in subregions, such as bays or shelves, which ease the material handling and (iii) increased number of pallets locations, since the height of the building can be better utilized. There are several different variants of storage equipment, that are suitable in different scenarios. The most common types of rack storage are presented below in *Table 3.4*.

Table 3.4: Common types of rack storage (Bartholdi and Hackman, 2019).

Type	Description	Advantages and Disadvantages
Single-deep racks	Racks with one pallet in depth	+ All pallets are always accessible - Less space efficient than multiple-deep racks, since it requires more aisle space
Double-deep racks	Racks with two pallets in depth.	+ Increased capacity, more pallets can be stored in the same area compared to single-deep - Risk of honeycombing, if each spot is dedicated to a single SKU - More difficult put-away and retrieval process - Requires special truck to reach the second pallet
Push-back rack	Racks that are multiple pallets in depth, where the pallets are "pushed back" when put-away	+ Increased capacity, more pallets can be stored in the same area compared to single-deep - Risk of honeycombing - Unsuitable for a FIFO-system
Drive-in rack	Racks that allow the truck to drive "into" into the frame, where the put-away and picking are from the same side.	+ Allows storage of pallets that cannot be stacked - Less flexible than other racking systems - Requires strong pallets, since they are only supported in the edges. - Increased labor costs, since it requires skilled forklift drivers
Drive-through rack	Racks that allow the truck to drive "into" into the frame, where the put-away and picking are from opposite side. Suitable for high volume products.	+ Allows storage of pallets that cannot be stacked + Suitable for FIFO - Less flexible than other racking systems - Requires strong pallets, since they are only supported in the edges - Increased labor costs, since it requires skilled forklift drivers
Flow rack	Racks that have deep tiled lanes with rollers. When the pallet is picked in the front, the following pallets flow to the front due to gravity. Thus, the rack is loaded from the back.	+ Suitable for FIFO + Space efficient - Less flexible than other racking systems - Requires strong pallets and packaging material.

3.3.2.2 Handling equipment

Handling equipment can be used to improve the warehouse operations. A main advantage is that the equipment can provide an efficient put-away and picking process, through enabling convenient storage locations (Bartholdi and Hackman, 2019). The most common types of handling equipment, and their respective general specifications, are presented below in *Table 3.5*. The same lift trucks are illustrated in *Appendix 7.4*. There are clear trade-offs between the different types in terms of reach, required aisle width and maneuverability. Thus, which handling equipment is suitable depends on the warehouse setting. For example the turret truck is not easily maneuverable outside of the racks, and requires precision in the aisles, which requires competent, and often more expensive, truck drivers. To conclude, handling equipment is an effective tool to improve warehouse operations but needs to be adopted to the specific conditions.

Table 3.5: Common types of lift trucks and general specifications (Bartholdi and Hackman, 2019).

Truck Type	**Description**	**Requirements**	**Req. Aisle Width**	**Max. Reach**	**Max. Velocity**
Counter-balance	Most common and versatile type of lift truck. Can handle one pallet at a time. Counter-balance refers to their heavy weight in the back, enabling it to lift heavier pallets. The sit-down version, which is used in the specifications below, has similar specifications as the stand-up version.	No special requirements.	3.7-4.6 m	6.1-6.7 m	21.3 m/min
Reach	Reach trucks are more nimble but able to reach pallets on a higher altitude.	No special requirements.	2.1-2.7 m	9.1 m	15.2 m/min
Double-reach	A reach truck that can handle two pallets at the same time. A reach truck is often supported by "outriggers", that extend under the forklift.	Requires a cm lift of the bottom level for deep-pallet racks.	2.1-2.7 m	9.1 m	15.2 m/min
Turret	Often referred to as a "narrow aisle truck". Uses a turret that turns 90 degrees, not requiring to turn within the aisle, and can thus fit into narrower aisles and has a higher reach.	Requires very flat floors, which are expensive. Usually also requires a guidance device, such as rails, wire, or tape, to guide driving in the aisle.	1.5-2.1 m	12.2-13.7 m	22.9 m/min

3.3.3 Automation

Warehouse automation comprises resources employed to move and store goods without the need for human operators. The level of automation of these resources, as well as their demands on WMS and connectedness, may vary. Most automated warehousing systems offer improved space utilization and smarter operations. AGVs can, when employed with an adept control system and appropriate warehousing prerequisites, dramatically benefit warehouse operations, for example in terms of cost and accuracy.

3.3.3.1 Warehouse automation

Warehouse automation, defined as operating handling equipment to move and store goods without the need for human operators has a long history (Rowley, 2000). Automated warehousing solutions include systems such as automated storage and retrieval systems, automated guided vehicles (AGVs), and sorting systems with a conveyor. The author states that the benefits of warehouse automation are seen in the form of for example higher space utilization, reduced operating costs, and decreased picking errors. However, the author asserts further, warehouse automation often requires significant initial investments and can reduce flexibility. The last especially being troublesome during demand peaks. Scalability is also an aspect to consider. These factors make careful analysis necessary to determine the impact of implementing a certain warehouse automation system (Kembro & Norrman, 2022).

The interest in automated solutions has increased in recent years and as a result the multitude of solutions exploring ways to optimize material handling (Kembro & Norrman, 2022). Some of these technologies are automated forklifts, shuttle systems and the already mentioned AGVs (Azadeh et al., 2019). Integrating these with the information systems employed has become an essential activity in the automated system business. Real time information being shared throughout the warehouse means vehicles/sorting systems can work seamlessly together, but also with human operators performing tasks. Although connectivity and automation are anything but mutually exclusive, there are many synergistic benefits, especially companies with less turnover and a smaller product assortment tend to choose one over the other (Kembro & Norrman, 2022).

Smart warehouses are conceptualized by Kembro and Norrman (2020) using a matrix defined by level of autonomy and connection. Relevant concepts are displayed in *Figure 3.5*. *Automated* warehouses contain automated solutions where, as above, there is no need for human operators. Such equipment can perform intended tasks and acquire information on the state of the process, it cannot, however, make decisions of what to do when the situation diverges from the instructions. A warehouse containing machines able to do that would be called *autonomous*. In *digital* warehouses one may find integrated information systems tracking processes and equipment. Thus, the systems obtain large amounts of data that can be used for for example systems tracking and improved forecasting. *Connected* warehouses also constantly monitor resources and products to perform real-time analysis of the system (Kembro & Norrman, 2022).

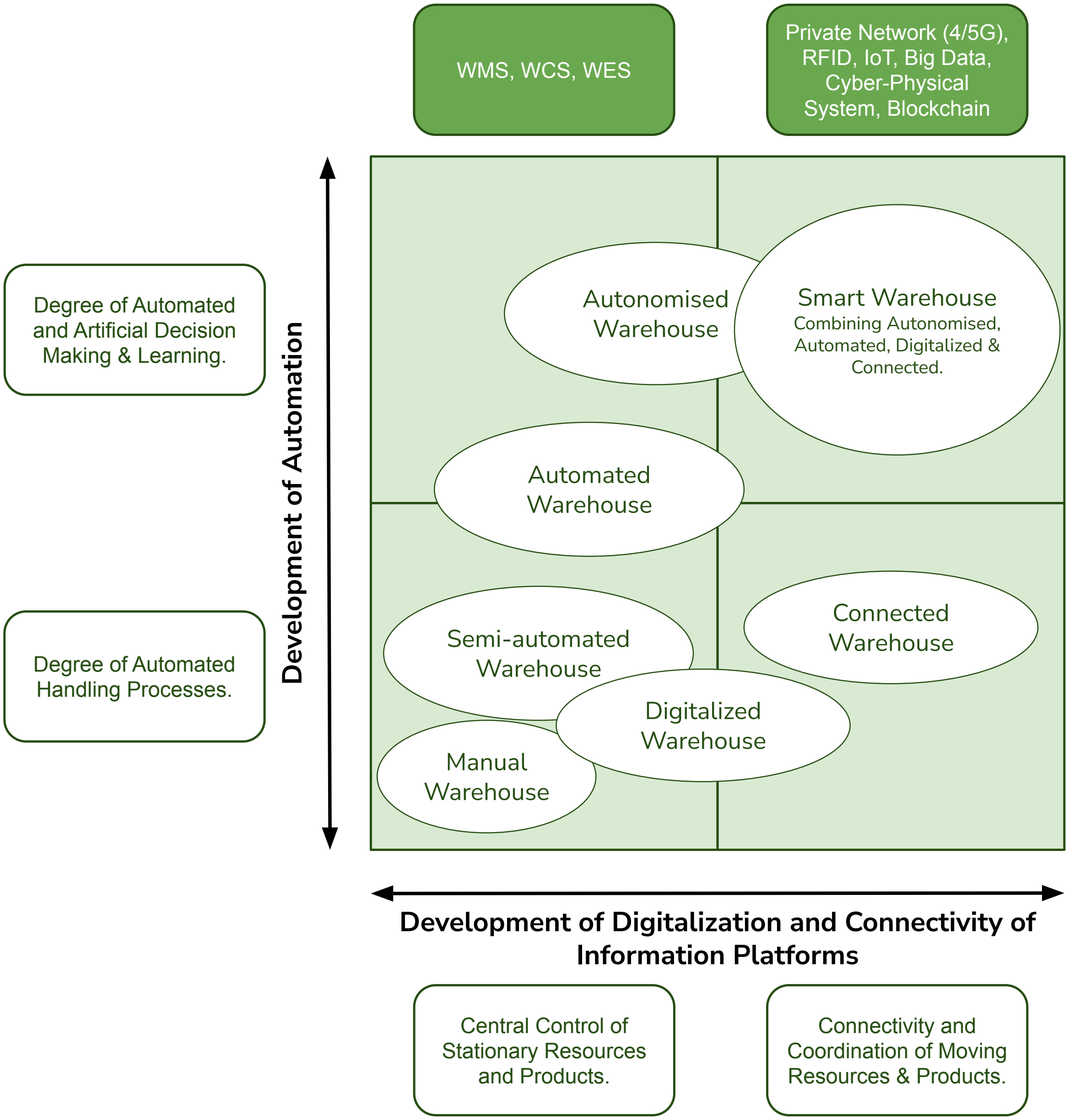

Figure 3.5: Conceptualization of smart warehousing. Adapted from Norrman and Kembro (2022).

3.3.3.2 Automated guided vehicles

In the optimization of the intralogistics AGVs plays a crucial part (Schulze and Wullner, 2006). AGVs have many use-cases and have been used in many sectors, where warehouses are a common application (Le-Anh and De Koster, 2006; Ullrich, 2023). The main advantage of the AGV is that it is automated. Using a machine instead of a human means that reliability increases, as the human factor is eliminated (Ullrich, 2023). It also increases availability. This corresponds to lower personnel costs, especially in multi-shift operations, and to perform operations during low operating times, such as during the night or the weekend. Additionally, the author further claims, the AGV enables transparent and organized flows of materials and information, enabling productivity improvement by optimization. The main disadvantage is that AGVs are generally expensive (Le-Anh and De Koster, 2006). They also require a more complex and advanced WMS to work properly. Another aspect is that the AGV can be classified as a “job killer”. However, a counterargument is that by automating more qualified jobs can be formed (Schulze and Wullner, 2006).

The different types of AGVs are suitable for different contexts. The AGVs differ in size, weight and capacity. In the context of this thesis, a unit load warehouse, there are three applicable categories; (i) Underrun AGV, (ii) Forklift AGV, and (iii) Narrow-Aisle AGV (Schulze and Wullner, 2006). The underrun AGV drives completely under the load, requring it to be elevated, and lifts it a few centimeters to transport it to the desired destination. This type of AGV has good track stability but is limited in lifting height and weight of the load. The forklift AGV is like an ordinary reach truck that can be operated automatically and manually. Additionally, it can come in the form of both pedestrian and ride-on model. The forklift AGV can be specially designed or as an automated series equipment. The authors further states that specially designed offer situational optimization the AGV, resulting in optimal integration, extended service lift and more efficient battery and battery charging. Automated series equipment is more standard in features, but generally cheaper, both the AGV and spare parts, as well as provided service. Lastly, there are narrow-aisle AGVs that can operate in narrow aisles and at high altitudes.

The functionality of AGVs relies on control- and navigation-systems. To control the AGVs an automated guided vehicle system (AGVS) is used (Le-Anh and De Koster, 2006). The AGVS is connected, and mastered, by the internal logistics system (ILS), such as an ERP or WMS (Ullrich, 2023). The author further asserts that the main objective of the control system is to coordinate the AGVs, which includes task prioritization, vehicle dispatching, routing and battery management (Le-Anh and De Koster, 2006). Two principal ways to navigate AGVs are fixed guide-paths and free-ranging. With fixed path navigation the AGV follows a fixed path using physical tracks on or below the floor (Ullrich, 2023). Wires, tape, or laser markers are typical markers. Free-ranging navigation uses support points or scanning devices to move freely in the warehouse. The author further states that navigation can be made using radio frequency identification, laser or GPS. There is a tradeoff between the freedom to easily choose between different travel paths and the reliability and simplicity of the system.

3.3.4 Information Systems

The ERP is a common information system with its core task of managing and integrating business processes in real time (Katuu, 2020). It is a software package that is composed of several modules such as finance, sales, production, and warehouse management providing information across the whole organization (Nazemi et al., 2012; Katuu, 2020). The advantages of using an ERP system are improved order management and control, accurate information on inventory, improved workflow, SCM, and better standardization of business and best practices (Nazemi et al., 2012). The authors further state that by integrating all functions, providing information to the right person at the right time through the ERP, enables improved informational efficiency.

A WMS is according to Bartholdi and Hackman (2019) a software solution that helps with managing personnel, storage locations, and inventory. The WMS typically knows the availability and dimensions of every storage location, consequently knowing where all SKUs are stored and their attributes. The WMS enables efficient operations through managing available resources by generating pick lists from customer orders and providing instructions on the most efficient way to pick requested items.

3.3.5 Labor & Safety

The quality of a warehouse floor and its markings are crucial elements that can both affect operational efficiency and safety for warehouse operators. A regularly used and well suited material for warehouse flooring is concrete (Bartholdi & Hackman, 2019). A well-maintained floor with clear markings that clearly shows where forklifts and people respectively should be, facilitates forklift traffic while additionally reducing the risk of accidents (de Koster et al., 2011). Simultaneously, a poorly maintained floor, or even one with uneven regularity, leads to increased wear and tear on forklifts (Garber, 2005). The tear on forklifts may also pose a threat to humans. Floors that deteriorate, or are unsuitable for excessive driving, may become a source of dust and particles that affect air quality negatively within the facility. The emitted particles are toxic to human health (Strelyaeva et al., 2019).

Controlling the temperature of a warehouse is pivotal for maintaining a comfortable working environment. Insulation plays a critical role in this, assisting in keeping the temperature from falling. Exposure to cold temperatures over time is an occupational hazard that poses a threat to worker health and productivity over time (Akbar-Khanzadeh et al., 2009). Insulation must however be complemented using natural or induced ventilation to also allow for cooling. A correctly adjusted temperature contributes to worker comfort and productivity by mitigating stress from working in harsh conditions. Adhvaryu et al. (2018) investigated the impact of fluctuating temperatures on workers, and found strong evidence for increased productivity during stable temperatures.

In terms of evacuation routes the Swedish Work Environment Authority (2020) requires that there is a door near every gate designated for truck traffic, unless moving through the gate is without risk. Those gates are also required to be marked and never blocked.

3.4 Analytical Tools

In this section of the report, the analytical tools are presented. The section is divided into two subsections covering different tools: (i) Activity Profiling Tools and (ii) Lean Tools. In the first the ABC-analysis and heatmap are presented as activity profiling tools. The second presents the lean tools. This includes a brief introduction of lean philosophy and the three lean tools used: (i) Value Stream Mapping, (ii) Spaghetti Diagram and (iii) Muda Matrix.

3.4.1 Activity Profiling Tools

Activity profiling is the measurement and statistical analysis of warehouse activities to understand how the warehouse functions (Bartholdi and Hackman, 2019). Simple statistical measures of the warehouse, the operations, SKUs and demand constitute the basis of the profiling. Although these simple and easily interpretable statistics are important, averages do not present the complexity of reality. Beyond average statistics there are two analytical tools used in activity profiling: (i) ABC-analysis and (ii) Heat maps. They are presented separately.

The ABC-analysis is an effective tool to analyze the demand of different products, by categorizing and then analyzing the picks for each SKU (Bartholdi and Hackman, 2019). In the ABC categorization class A contains a small fraction of the SKUs that stand for most of the activity. While B and C are classes that are increasingly large but with less activity. The division between classes is often a fixed percentage number. However, there are no exact limits that should be used. In this thesis, an 80/10/10% division was chosen.

The tool originates from the Pareto principle, or 80-20 rule, stating that, in a warehousing context, only 20 percent of the SKUs constitute 80 percent of the activity. Generalized: a minority of the operations constitute most of the activities. If this is the case, the demand is said to be Pareto-distributed. The analysis can be done by analyzing two different aspects: number of picks and cumulative picks. An example of the picks plotted for each SKU is illustrated in an ABC-diagram in *Figure 3.6.* Here it can be seen that the demand is skewed, or Pareto-distributed, since the most popular SKUs have the most picks. By categorizing the SKUs into classes, ABC-classification, the figure can be used in an ABC-analysis.

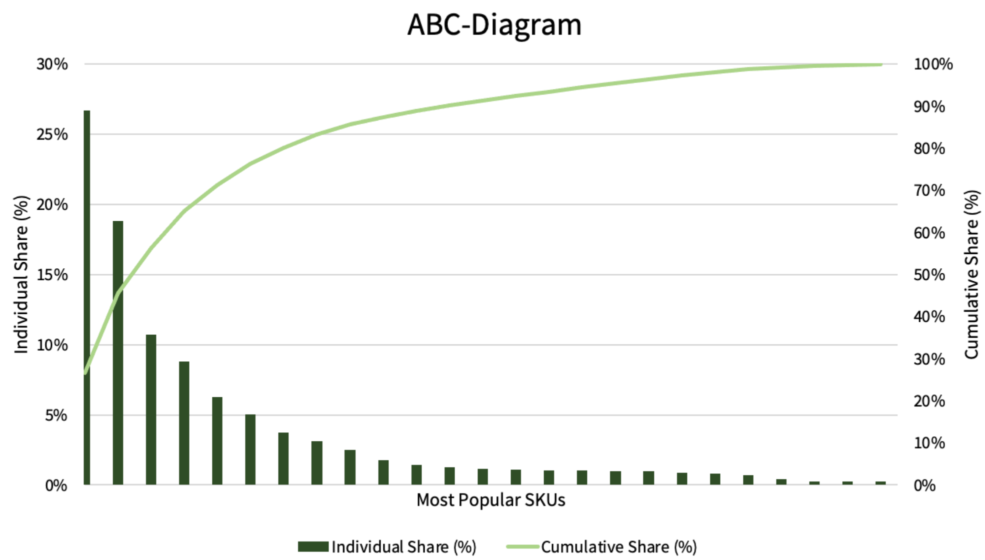

Figure 3.6: ABC-Diagram. Adapted from Bartholdi and Hackman (2019).

The Heat Map is a visualization tool used to identify crowded areas by analyzing movement (Kembro et al., 2017). The map tracks frequency in a certain area, often bins or pallet locations in a warehousing context. Where an increase in activity is matched with the increasingly intense color scheme of a particular area. The frequency measured can be picks or number of units in stock. The authors further claim that the goal of the Heat Map is to identify frequently visited location and bottlenecks. This can provide input for configuration decisions, such as layout and SKU placement. The tool is an effective way to illustrate information, based on object positions, which helps the viewer (Cogo et al., 2020). An example of a Heat Map is illustrated in *Figure 3.7*.

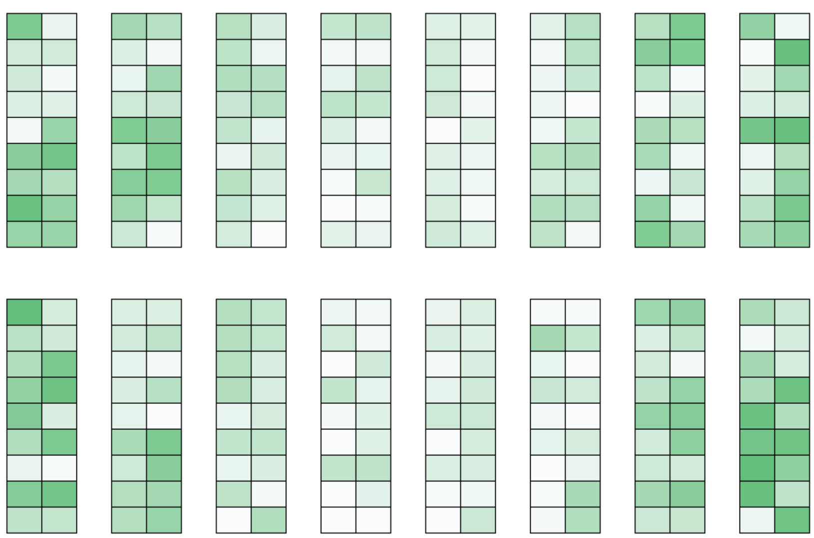

Figure 3.7: The Heat Map. Adapted from Bartholdi and Hackman (2019).

3.4.2 Lean Tools

In this section of the report the lean tools are presented. The chapter is divided into two subsections: (i) Philosophy and (ii) Tools. In the first subsection the concept of waste and value, a central concept of lean, is presented and exemplified with the seven kinds of waste. Secondly, the analytical tools are presented. These include (i) UML-diagram, (ii) VSM, (iii) Spaghetti Diagram and (iv) Muda Matrix. By utilizing these analytical tools, analyzing different aspects, a complete picture of the warehouse can be obtained.

3.4.2.1 Philosophy

A central idea in lean philosophy is the separation of value and waste. All operations can be categorized into three categories: (i) non value-adding (NVA), (ii) necessary but non value-adding (NNVA), and (iii) value-adding (VA) (Hines and Rich, 1997). The VA-activities are to be pursued and the NVA-activities to be eliminated. The third category could be described as a “necessary evil”, since the activities are not directly value adding but necessary. Lean is not only a combination of tools, but a philosophy. Womack and Jones (1996) presented five lean principles; (i) define *value*, as defined by the end customer, (ii) map the *value stream*, which is the combination of all activities to create a product, (iii) create a *flow*, in the value stream, (iv) establish *pull*, to limit the work-in-progress, and (v) pursue *perfection*, by making continuous improvements. By utilizing the principles wastes are eliminated and operations become more efficient. While the lean concept originates from a production environment, it is increasingly used in a warehousing context. Reducing waste in warehouses, a central idea in lean, has been seen to improve operational and distribution performance (Abushaikha et al., 2018). The seven different types of waste, and how they are expressed in a warehousing context, are presented in *Table 3.6*.

Table 3.6: Wastes in a warehousing context (Hines and Rich, 1997; Abushaikha et al., 2018).

Waste	In a Warehousing Context
Overproduction	Excess stock, due to receiving goods that are not in demand leading to congestion.
Waiting	Inefficient use of time, resulting in inactivity and stoppage of inventory movement.
Transportation	Excess movement, often due to a poor layout.
Inappropriate processing	Complicated solutions are implemented for performing simple tasks, often due to manual elements.
Unnecessary inventory	Too much inventory, resulting in increased lead time, inventory storage cost, and interferes the value stream.
Unnecessary motions	Redundant actions, which are unavoidable for the worker.
Defects	Subpar complete orders, which do not live up to the expectations of the customer.

3.4.2.2 Tools

The lean tools are used to get a complete picture of the warehouse and identify and eliminate waste. The used procedure is inspired by, but adapted to the thesis, the "integrated approach for warehouse analysis" by Dotoli et al. (2015). Compared to the original framework the Spaghetti Diagram has been added and irrelevant steps, to this thesis, have been removed. The goal of the approach is to identify waste and eliminate inefficiencies in a warehouse, using lean tools and principles. The integrated approach is presented in *Figure 3.8*.

The approach utilizes three different tools: (i) Value Stream Mapping (VSM), to measure and identify the inefficiencies, (ii) Spaghetti Diagram (SD), to map and identify waste in the physical movements, and (iii) Muda Matrix, to quantify and rank the inefficiencies. These tools are used to map the current situation, identify improvement areas and serve as a template for an improved warehouse. Thus, the mapping tools, VSM and SD, are used to visualize the current state. Then the Muda Matrix is used to rank the inefficiencies. After an assessment a new solution is identified, where updated maps of the VSM are created to visualize the future state. By utilizing the three different methods, focusing on different aspects, the complete toolbox gives a solid base for change. In the following text each of the tools are presented.

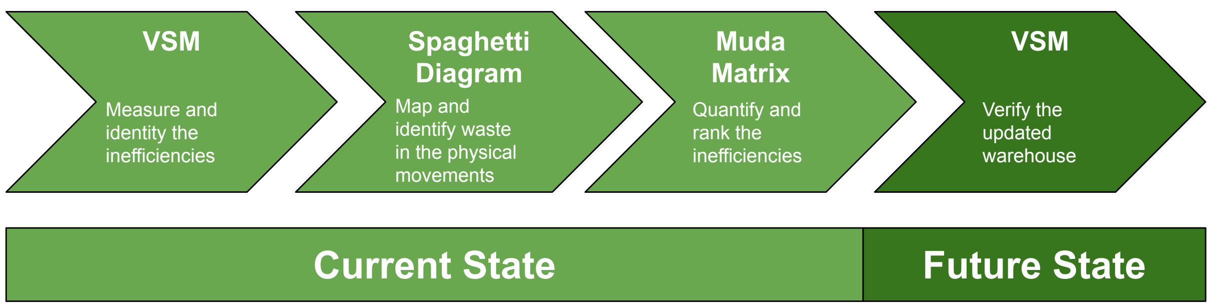

Figure 3.8: Integrated approach for warehouse analysis, inspired by Dotoli et al., (2015).

Value Stream Mapping

Value stream mapping is a useful tool to identify wastes occurring in the process. A value stream is the combination of all activities, both value and non value-adding, required to bring a product to the customer (Rother, Shook, Womack and Jones, 1999; Dotoli et al., 2015). The Value Stream Map also analyzes the flow of material, the physical product, but also of information which informs the following step in the process how to proceed (Rother, Shook, Womack and Jones, 1999). By utilizing Value Stream Mapping anomalies and unnecessary activities in a warehouse are easily identified when mapped (Dotoli et al., 2015). Thus, it is easier to determine the source of inefficiencies and remove them.

The Value Stream Mapping is performed in four distinct steps; (i) identify the target product family to map, (ii) draw the current state of the value map for a product family, (iii) asses the current state map, and (iv) draw the future state map (Dotoli et al., 2015). Initially, the delimitations of the mapping, the starting and finishing point, are determined. The product family, which consists of products that that share similar characteristics in terms of processing and production steps, are determined (Rother, Shook, Womack and Jones, 1999). Following, the current state map is to be drawn. The map includes detailed information of the material and information flow in terms of times, costs and delays by utilizing standardized icons for each part (Dotoli et al., 2015). Then, the current state map is assessed, by determining whether each process activity is, or is not, value adding. The authors further asserts that when wastes and inefficiencies are identified they are marked on the map with a bomb symbol. Finally the future state map is drawn, after the assessment of the current state map and the Muda Matrix, see *Paragraph 3.4.2.2*. An example of a current state Value Stream Map is illustrated in *Figure 3.9*.

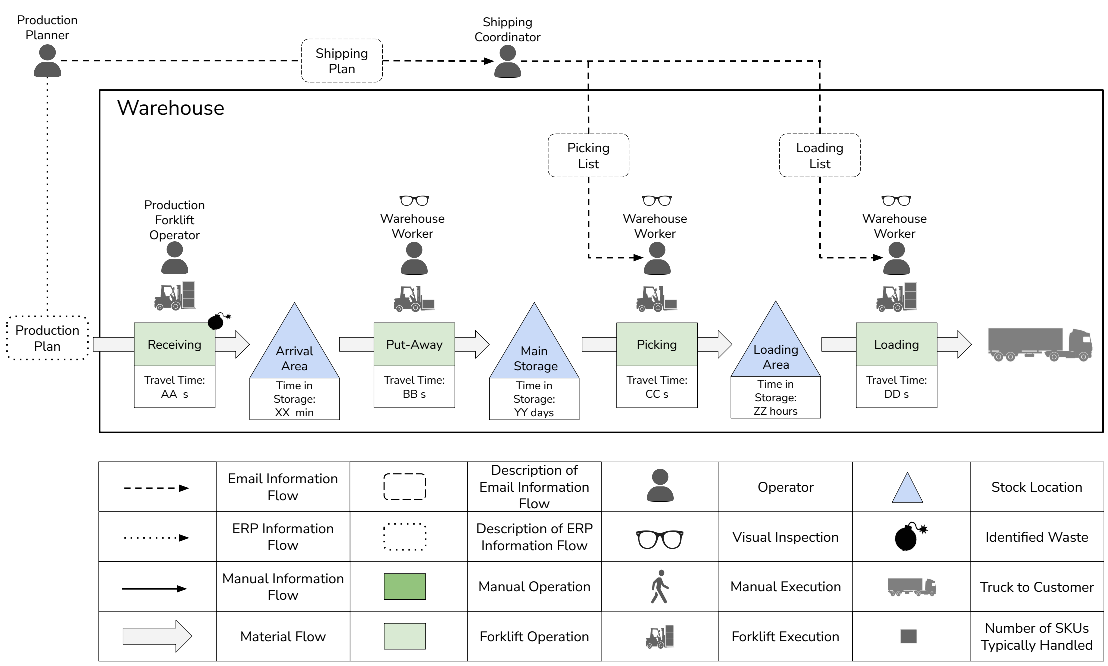

Figure 3.9: Example of a current state Value Stream Map, adapted from Dotoli et al., (2015).

Spaghetti Diagram

A Spaghetti Diagram is a visual tool that illustrates the physical movement of an object, such as a product, through the processes in a value stream, according to Pyzdek (2021). The author further notes that a main advantage is the ability to identify non-value and value-adding distances traveled, by illustrating complexity and congestion in the processes. The diagram provides a visual overview of how the process is, and how it should be.

The creation of a Spaghetti Diagram is made in five steps: (i) identify the start and end points for the value stream, (ii) find or create a graphical or pictorial layout of the whole value stream, (iii) categorize the product, or product families, and study the actual flow, (iv) have the employee perform the task, and (v) draw the map, where each line in the diagram represents a traveled distance in real life. It is essential to track the physical distance traveled as thoroughly as possible to accurately represent the physical process. To separate the different actions performed different colors can be used. Additionally, a Spaghetti Diagram can include numbered stops at each location, to further illustrate the direction of the flow. An example of a Spaghetti Diagram is illustrated in *Figure 3.10*.

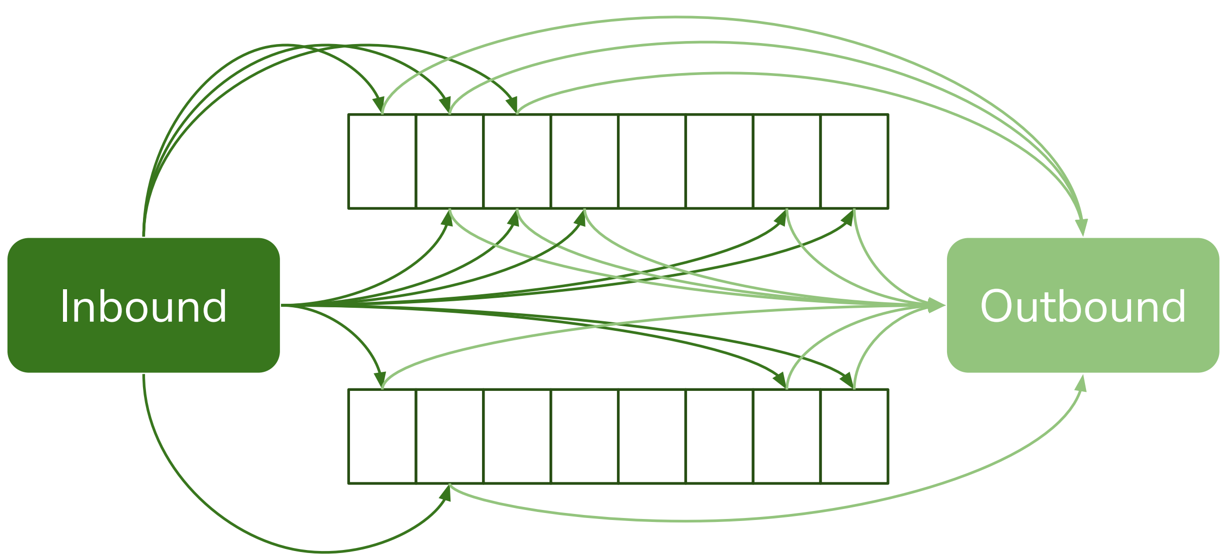

Figure 3.10: Example of a Spaghetti Diagram, adapted from Pyzdek (2021).

Muda Matrix

The Muda Matrix is a useful tool to quantify and rank problems (Dotoli et al., 2015). The tool has its origin in the "Genba-Shikumi" technique, where Genba is Japanese for "the real place" and Shikumi is "something with different parts that are organized to work together under some intention". The authors further claims that the principal point is that the most effective way to improve processes is by observing them, since problems are directly visible. Thus, when an anomaly occurs, management should go to the place where the problem is located to grasp the width and cause. In this case this principle corresponds to interviewing the personnel working closest to the problem at hand. The use of the Muda Matrix is closely tied to the Pareto principle, that 80% of the effects are derived from 20% of the causes. Thus, by addressing the most troublesome wastes the largest improvement will be seen.

The Muda Matrix used in this case is inspired by the one presented by Dotoli et al., (2015) but simplified to fit the purpose. The matrix consists of two vectors, observed problems and wastes. An example of a Muda Matrix is presented in *Figure 3.7.* The main purpose is to identify and rank the different anomalies occurring in the warehouse. Additionally, the anomalies are connected to waste, to categorize which waste is most common. The process to create the Muda Matrix consists of two steps: (i) employee ranking and (ii) creating the matrix. In the first step the employees working in relation to the warehouse are asked, during the interviews, to describe and rank the problems they are perceiving related to the FGW and its operations on a scale from one to seven, where seven has a large impact. In the second step the authors perform an assessment, based on the input of the employees, where the problems are connected with corresponding waste, and ranked, from one to seven, depending on the severity. The assessment is done from a combination of the current state VSM and interviews with employees involved with the FGW.

Table 3.7: Example of a Muda matrix. Adapted from Dotoli et al., (2015).

#	Observed problems	Waste 1	Waste 2	...	Waste w	Sum
1	Problem 1					**1**
2	Problem 2	1			1	**2**
⋮	⋮		1			**1**
p	Problem p	1		1		**2**

In Dotoli et al's use of the Muda Matrix a 5-point scale is used, but a 7-point scale can be favorable to use. A 7-point Likert scale offers more options, allowing for more precise responses than a 5-point scale (Joshi et al., 2015). This helps in understanding subtle differences in opinions more clearly. The 7-point scale also reduces the tendency of respondents to pick middle options, leading to more distinct and meaningful data. Thus, making it a practical choice for capturing a wide range of opinions effectively.

3.5 Analytical Framework

The analytical framework defines the outline for the data collection and analysis in the upcoming chapters. It includes the practical tools presented in this chapter. That is the contingency framework for a warehouse configuration and the analytical tools. The analytical framework is presented in *Figure 3.11*. In the figure the connection clearly illustrates the connection between the frameworks, including the analytical tools, and the research objectives. The goal of the thesis is to reach these objectives. Thus, all activities and analyses conducted help contribute to reaching the objectives. Finally, the objectives should help reach the deliverables, with the main deliverable being a new warehouse configuration.

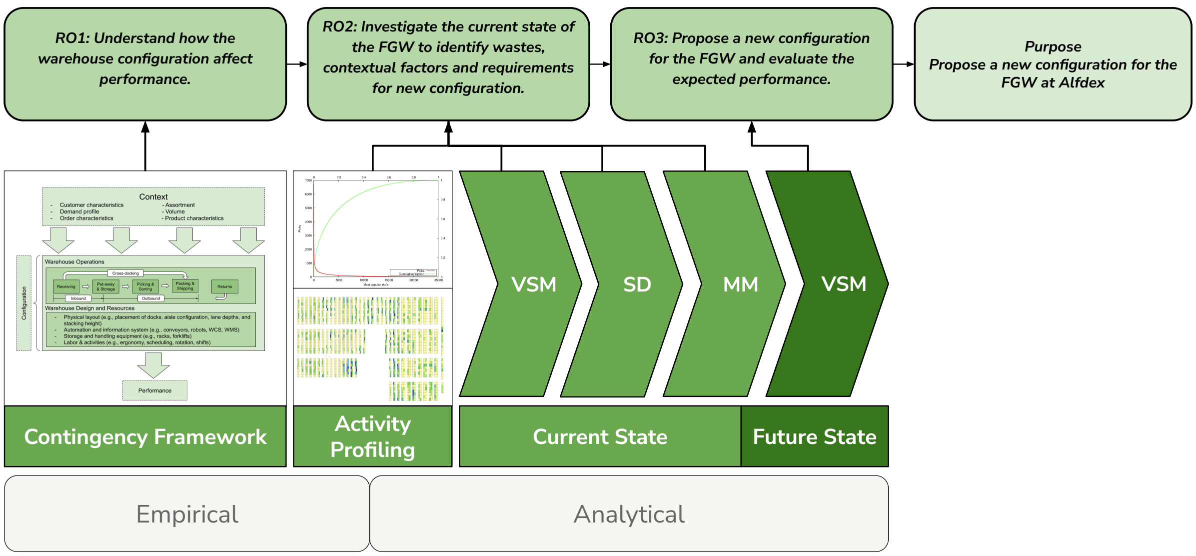

Figure 3.11: Analytical framework.

The thesis framework combines the practical and theoretical efforts used in the thesis to reach the research objectives. To reach these objectives not only the tools are of interest, but also the methodological aspects. The thesis framework is presented in *Figure 3.12*. To understand the connection between warehouse configuration and performance, RO1, the literature review and company visits are of interest, not only the contingency framework. The same is true for the second objective, where the data analysis is a crucial part of the investigation of the current state of the warehouse. Thus, the master framework summarizes and illustrates the connection between the first three chapters of the thesis.

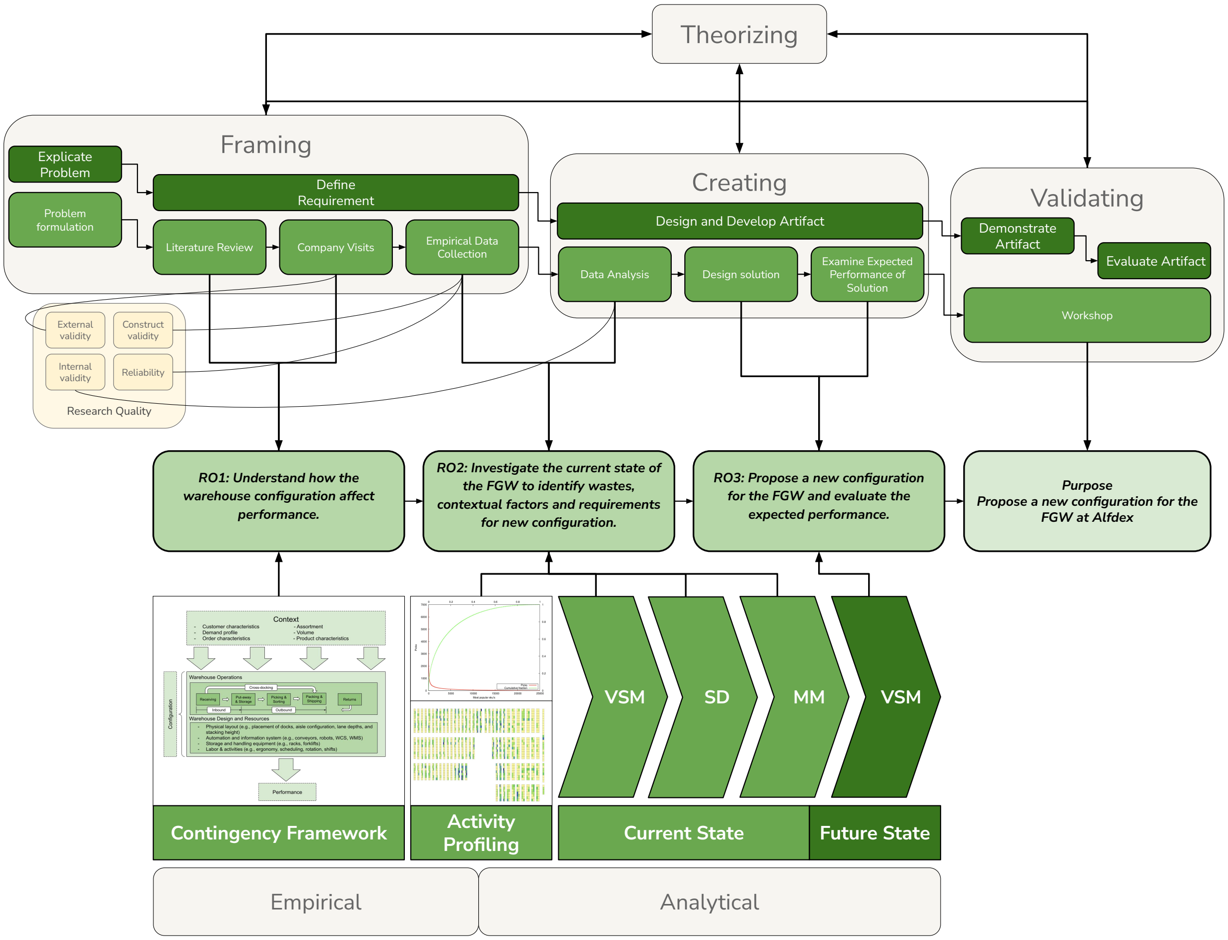

Figure 3.12: Thesis framework, combining the methodological and analytical framework.

4 EMPIRICAL FINDINGS

This section of the report presents the empirical data collected during the study, both quantitative and qualitative data from observations, interviews, and secondary data sources. Visual tools are used throughout for clearer interpretation of the raw data in a simple and structured format. The section follows the contingency framework and is structured in the order; Contextual factors, Warehouse Operations, Warehouse Design & Resources, Employee Problems - Identification, and lastly Company Visits.

4.1 Contextual Factors

This section accounts for the contextual factors that shape the environment in which Alfdex operates. It starts with looking at the number of SKUs in the FGW over the measurement period. Then SKU-types and their dimensions, and respective sales, are presented. Subsequently, sales of SKUs are looked at, per customer and article. Lastly the expectations for growth and future demand are accounted for.

4.1.1 Stored SKUs

The number of SKUs in storage, during the measurement period, is illustrated in *Figure 4.1*. This includes all SKUs placed in storage in the FGW, excluding the arrival- and loading area. Most of the SKUs include finished goods SKUs. However, there are also additional material SKUs, such as packaging material, repackaging, and old machinery, that on average aggregates to 150 SKUs. The average number of SKUs in storage in the FGW is 596 SKUs.

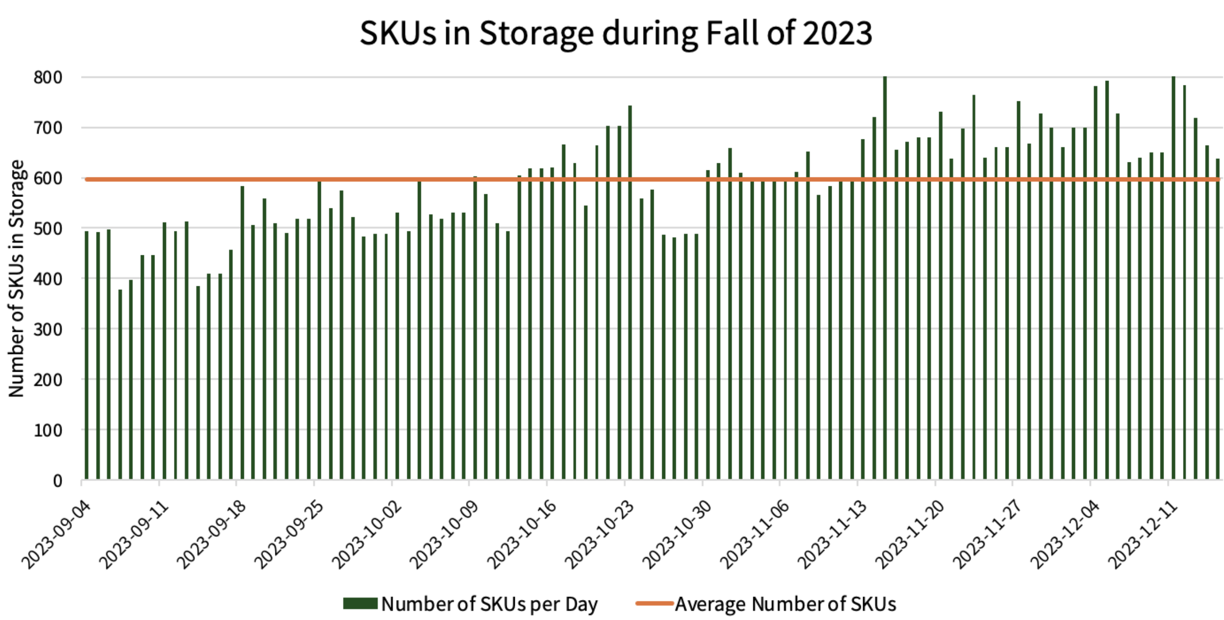

Figure 4.1: SKUs in FGW, for each article during fall of 2023.

The number of SKUs in the loading area, see explanation in *Subsection 4.3.1*, is illustrated in *Figure 4.2*. The shipping plan entails shipping, which operates on weekdays. Thus, the average number of SKUs in the figure is calculated for the weekdays only and aggregates to 87 SKUs. However, for the days of the weekend, which is used in the figure the number of SKUs in the loading area were set as the shipped quantity for the following Monday, as there is generally no production during the weekend.

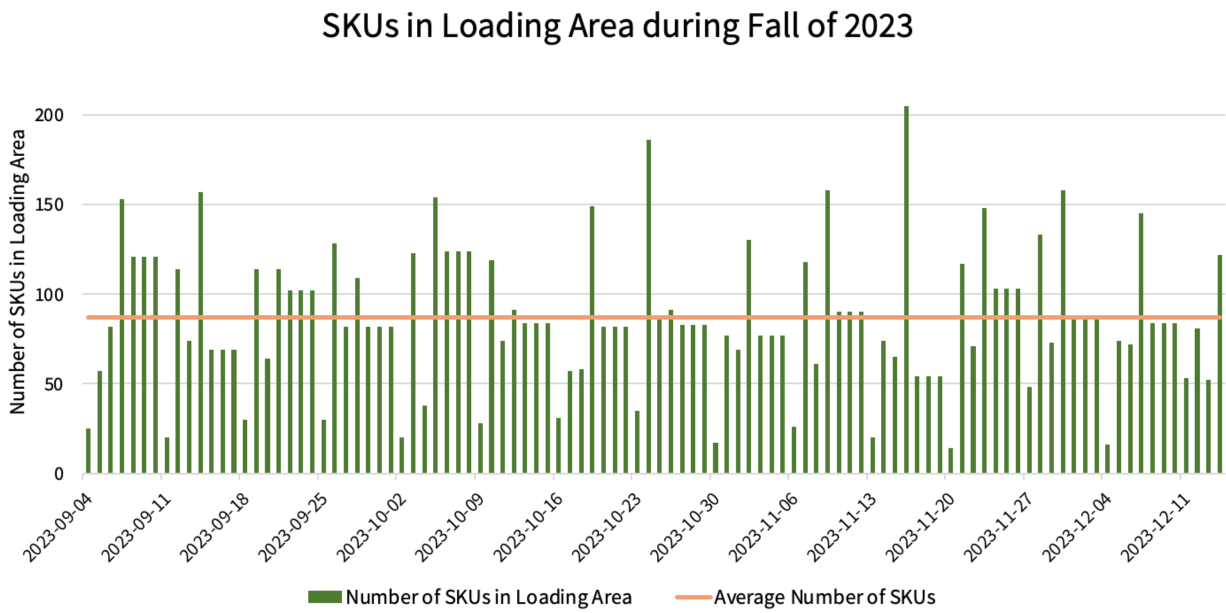

Figure 4.2: SKUs in Loading Area during fall of 2023.

4.1.2 SKU Characteristics

The FGW is a unit-load warehouse that encompasses different categories of SKUs. The distinction can be made between three principal categories: wooden EU-pallets, cardboard-pallets and lattice boxes.

Wooden EU-pallets are the most common type in the warehouse and come in several sizes and shapes. The distinctive feature of these pallets is that they have "collars," which determine the height of the SKUs based on the number of collars. An example of a wooden EU-pallet, with four collars, are illustrated in *Figure 4.3*. The number of collars ranges between one and four for finished goods pallets, but is most commonly three. The standard three-collar pallet often contains 48 units. Wooden EU-pallets come in different variants for different customers; *Customer B* and *C*, see *Subsection 4.1.3*, have their own distinct packaging materials, marked with their company name and color. Standard Alfdex wooden EU-pallets are primarily used to ship goods to *Customer D* and other customers. Additionally, EU wooden pallets are available in full and half sizes; the full pallet is 120 cm long and the half is 60 cm, both 80 cm wide. The height of a pallet collar is 19 cm, making a standard three-collar pallet 72 cm.

Figure 4.3: An EU-Wood Full Pallet with four collars.

The lattice box is a kind of metallic SKU that is similar, but smaller, compared to a standard wooden EU-pallet, see *Figure 4.4*. The lattice box is used to satisfy the requirements of *Customer A* and only contains 24 units per SKU. The lattice box has a length of 100 cm, width of 60 cm and a height of 69 cm. Due to the shorter length of the boxes, compared to wooden EU-pallets, they are stored with their longer side in the front. Thus, more SKUs can be fitted into each bin. The lattice box shares similar stacking functionalities as the other variants, and the stacking policy for these pallets is a maximum of three pallets.

Figure 4.4: A Lattice Box at Alfdex.

The last category of SKUs are the cardboard-pallets. These are stored on full size wooden EU-pallets, but instead of collars are stored in a box with cardboard-material, see *Figure 4.5*. The cardboard-pallets all come in the same dimensions, with a length of 120 cm, width of 60 cm and height of 66 cm. The cardboard-pallets are primarily used for *Customer D* and contains 60 units per pallet. Additionally, it is used by *Customer A*, for some of their locations, and for some of the *Remaining* customers. However, in these cases the cardboard-pallet contains 48 units per SKU.

Figure 4.5: An EU-Cardboard SKU at Alfdex.

The type of SKU, in terms of material, depends on the article and customers. The distribution of different types of SKUs sold during 2023 is illustrated in *Figure 4.6*. From the figure full wooden pallets, lattice boxes and cardboard SKUs are the most common in the FGW. The column named *varying* are for SKUs whose material type differ from time to time. This primarily depends on the specific customer, but also on the requested quantity.

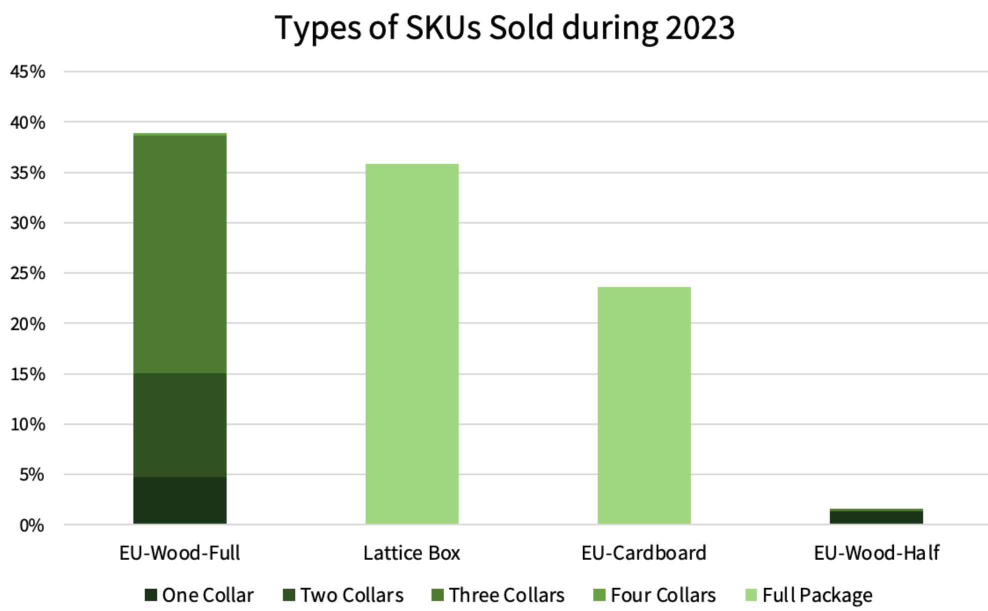

Figure 4.6: Distribution of types of SKUs sold during 2023.

4.1.3 Current Demand

The number of sold SKUs per customer during 2023 is illustrated in *Figure 4.7*. The number of SKUs were chosen as appropriate, in contrast to units, as the number of units per SKU varies between different SKUs, as described in 4.1.2. Additionally, the new configuration is to be dimensioned after the capacity of SKUs. The customers were anonymized and ranked, *A - Remaining* in the figure, where *Customer A* has the largest number of sold SKUs. *Remaining* consists of the remaining customers with demand below 4%. The plot illustrates the relative volumes of each customer, which affect the proposed configuration's storage policy.

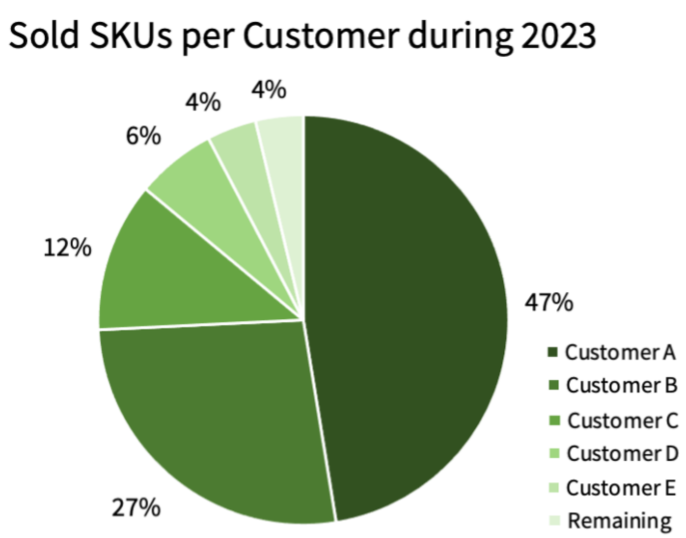

Figure 4.7: Sales per customer, number of SKUs during 2023.

The number of sold SKUs per Article Number during 2023 is illustrated in *Figure 4.8*. The article numbers were anonymized and ranked, *1 - Remaining* in the figure where *Article 1* has the largest number of sold SKUs. *Remaining* is the summary of the remaining article number sold in smaller quantities, below 2% individual share. In the figure each article number is color-coded per customer, with the corresponding color seen in *Figure 4.7*. The plot illustrates the relative volumes of each article number which will later affect the proposed configuration and storage policy.

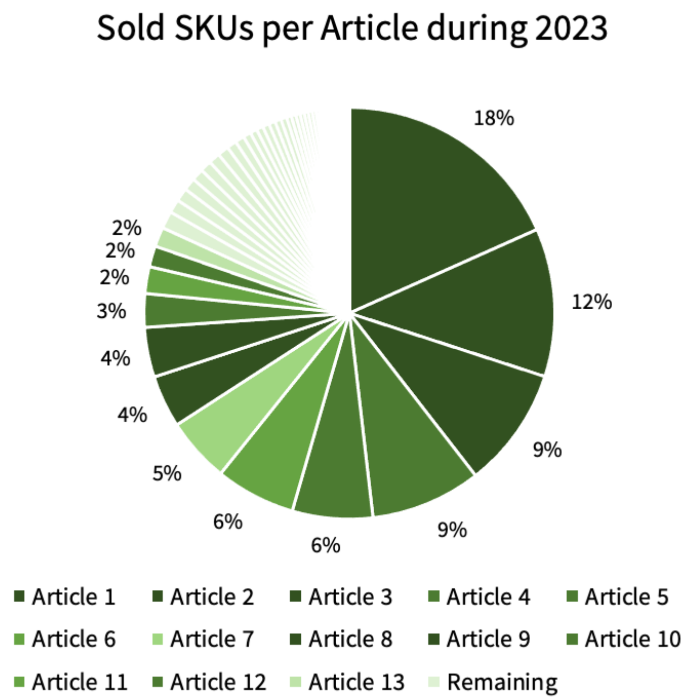

Figure 4.8: Sales per article, number of pallets during 2023.

4.1.4 Future Demand

The future demand is expected to remain at the same level in terms of volume but increase in the number of product variants. The outlook suggests that the shift towards electric trucks in key markets will decrease the demand for products that currently dominate sales. A significant milestone is January 1, 2026, when the Euro 7 regulations come into effect. It is anticipated that, with this date in mind, sales of components will shift towards catering to a demand for replacement parts for older models. Although the overall sales volume is expected to remain similar or slightly lower than current levels, the composition of these sales will likely be more diversified, with larger product categories being divided into various versions. The emergence of new customers under the current scenario seems unlikely. However, volumes could see a positive impact if markets with minimal or no emission regulations, such as certain regions in Africa and South America, decide to implement measures like those in the major markets.

4.2 Warehouse Operations

The warehouse operations section, in line with the contingency framework and stated delimitations, considers all operations from the moment the goods arrive in the warehouse until they leave. For Alfdex that entails receiving, put-away, picking, marking and loading. These are shown in *Figure 4.9*, based on the layout presented in *Figure 4.10*, where the lines also represent the specific operations that the time-measuring was based on. Note that picking is divided into *Pallet Flag Picking*, operation C, and *SKU Picking*, operation D. Additionally, the operations that take place within an area, see operation C and E, have been illustrated with two arrows in a circle. The time it takes to perform each operation is presented in their respective section as well as in a retrospective summary. Note that each time is the time it takes for a travel which constitutes the operation, that is the one-way travel time. Also note that up to three EU-pallets or six lattice boxes can be transported at once, which influences the time per pallet. As no pallets are transported during *pallet flag picking* and *marking*, they are instead reported as the average time per pallet for the whole procedure.

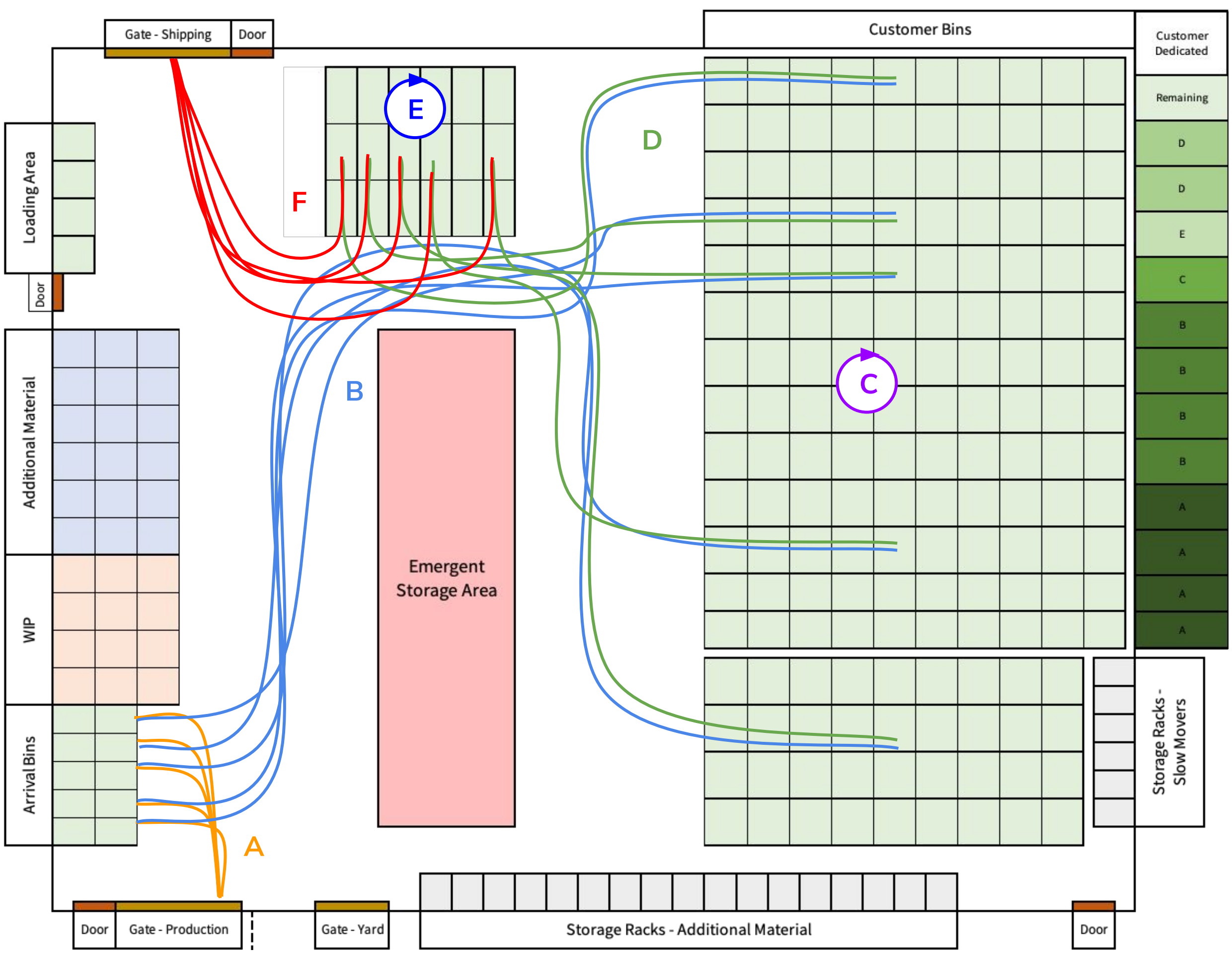

Figure 4.9: Layout of the FGW with every operation. A: receiving, B: put-away, C: pallet flag picking, D: SKU picking, E: marking and F: loading.

4.2.1 Receiving

Pallets arrive in the FGW by reach truck from the production gate and are put in the arrival bins, see *Figure 4.9*, illustrated by operation A. The operation is performed by a production worker from the manufacturing part of the facility. It takes nine seconds from gate to arrival bin, deviating slightly depending on utilization of the arrival area.

4.2.2 Put-Away

Put-away, demonstrated as operation B, entails transporting pallets from the arrival to the customer bins. It is performed by warehouse workers utilizing a truck. The pallets are not scanned, meaning the operator must determine which bin to place the pallet in. The pallets are placed corresponding to customers, depending on article. When available space in the dedicated bins is scarce, the pallets are placed in the informal extra bins. The decision is independently made by the warehouse worker. Performing the put-away operation of one pallet or pallet stack takes between 18 and 22 seconds with a mean of 20 seconds. Slight variances were observed depending on the utilization of the bins in area 3 but also the contemporary state of the emergent storage area and loading area which restricts the drive path. This corresponds to 6.7 seconds per SKU under the assumption that three pallets are handled per operations, as is the most common case.

4.2.3 Picking

The picking-operation is divided into the picking of *Pallet flags*, operation C, and *SKUs*, operation D. The actions are performed by different staff at different times. The first is performed, usually before midday, by the those working shipping administration and has the function of checking which specific pallets are to be sent. The second is the actual picking of said pallets for next-day shipments, which is performed by the second shift warehouse worker in the afternoon once the current day's loading area has been cleared, by being shipped.

Pallet Flag Picking
The "pallet flag" is a paper containing SKU information placed on each SKU. There are several reasons why the pallet flag system is used. The main one is to ensure that the SKU is physically located in the FGW in the correct quantity, and not only present in the ERP system. Secondly, it acts as a guide for the SKU picking, described in the upcoming section. Lastly, it contains information about the SKU, such as article number, number of units and weight, which is used in the shipping process.

The pallet flag picking operation commences once the shipping plan for the next day has been determined. The plan is sent from the production planner to the shipping coordinators, usually in the morning, containing information of the quantity of each article to be shipped. The plan also entails the status of each article, where oftentimes the items are in the FGW, but at times produced on the day of shipping. The number of SKUs, corresponding to the number of units, is calculated. Then the number of SKUs of each article to be picked is retrieved from the ERP system. When only a fraction of SKUs is to be picked, the shipping coordinators must follow FIFO by manually searching for the oldest SKUs.

After the preparation, the pallet flag picking is often done in a pick-wave, during the forenoon, for the pallets that are ready in the FGW. If there are any pallets still in production, or to be produced in the current or following day, the process is repeated continuously throughout the current, and the following, day. Once the pallets have been located their pallet flags are ripped off, which marks them for later picking. The papers are then used administratively to register the pallets on the order, which enables double checking of both correct article and quantity of pallets. The average pallet flag picking time was 38 seconds per SKU.

SKU picking
Once the loading area has been cleared and shipment administration is performed, after the pallet flags have been picked, the SKU picking can be performed. The starting point is an email sent from the shipping coordinators to the warehouse workers, usually in the afternoon, containing information about which articles should be picked and in what quantity. With the current layout of the warehouse that entails moving the marked pallets from the customer bins to the loading area, i.e. performing operation D, see *Figure 4.10*. The SKU picking is performed in a picking wave, during the afternoon, for all the SKUs that are ready. The SKUs are picked in quantities ranging from one to three at a time, depending on if the whole stack is to be picked. The SKUs are then stacked three pallets high in the loading area.

The warehouse worked is directed by the picking list, emailed from the shipping coordinators, and the lack of a pallet flag on the SKUs. If the ready SKU, missing a pallet flag, are blocked, by SKUs stacked in front of them, they need to be temporarily stored elsewhere to allow for retrieval. The time the SKU pick-wave takes depends on several factors. The main one is where the SKU to be picked is located, if the SKU is located behind eight SKUs it will be harder to retrieve, as the SKUs in front of it will have to be temporarily located elsewhere. Additionally, it depends on the number of pallets in storage. When the stock levels are low it is easier to find the SKUs to be picked, and there are fewer congesting pallets.

Additionally the picking is dependent on the customer. Some customers have many different product variants which makes picking more difficult. Both in terms of the pick list, customers with many variants often order many variants in smaller quantities, but also the storage, it is easier to locate pallets with fewer variants, as the products are often stacked with pallets from the same production batch. To conclude, the SKU picking depends heavily on the location of the SKU, the number of pallets in storage and the customer. Thus, it is dependent on the day of the week, as different days have different amounts and shipments to different customers, see *Subsection 4.1.1*. The measured time was nonetheless approximately 18 seconds per travel. Thus, assuming each operation entails three SKUs, this corresponds to 6 seconds per SKU.

4.2.4 Marking

The operation of marking is performed on the SKUs once they are in the loading area, illustrated as operation E in *Figure 4.10*, by the shipping coordinators. The marking provides shipping information, including destination and customs documents. The operation is performed manually, and the papers are stapled onto the SKUs. Performing this takes 12 seconds per pallet. The time increases somewhat when the number of pallets increase.

4.2.5 Loading

The last operation performed on the pallets is the loading. The pallets are transported from the loading area through the gate and unto the truck. The truck is parked closely outside the building, approximately 20 m from the gate. Depending on the customer, the type of truck and the available space on the truck, the pallets are stacked at different heights. To be able to fit onto the truck the pallets must sometimes be stacked four pallets high. To allow for measuring the time of the loading, operation F, the measured time has been limited to the action of picking up the pallets, including eventually moving blocking pallets out of the way, and transporting them to the gate. This takes 11 seconds per travel. Hence, assuming three SKUs handled per travel, this corresponds to 3.7 seconds per SKU.

4.2.6 Summary of Operational Times

The handling times for a SKU in the above-mentioned operations adds up to 1 minute and 15 seconds. The complete set of operations, and their respective times, are summarized in *Table 4.1*.

Table 4.1: Summary of operational times in FGW, seconds per travel

Operation	**Time per SKU(s)**
Receiving	9
Put-Away	6.7
Pallet Flag Picking	38
SKU picking	6
Marking	12
Loading	3.7

4.3 Warehouse Design & Resources

This section looks at the design and resources of the FGW. Initially the layout is portrayed and looked at in detail followed by what this means in terms of pallet positions and current equipment directly used for storing SKUs. The obtained secondary data on number of SKUs in each section of the FGW at a given time is then presented along with what this entails in terms of utilization of the current spaces. Subsequently the resources that are available in terms of employees and the current system are described.

4.3.1 Physical Layout

The physical layout of the FGW is illustrated in *Figure 4.10*. A more realistic portrait of the FGW, can be found in *Appendix 7.4*. The customer bins, that will be described more closely in *Paragraph 4.3.1.2*, are marked by the customer they are dedicated to, on the right-hand side in the figure. The capacity of each bin is represented by the number of EU-pallets they can accommodate, in the top of the figure. Additionally, for the customer bins, the capacity for lattice boxes is illustrated. The layout areas will be described further in the text below.

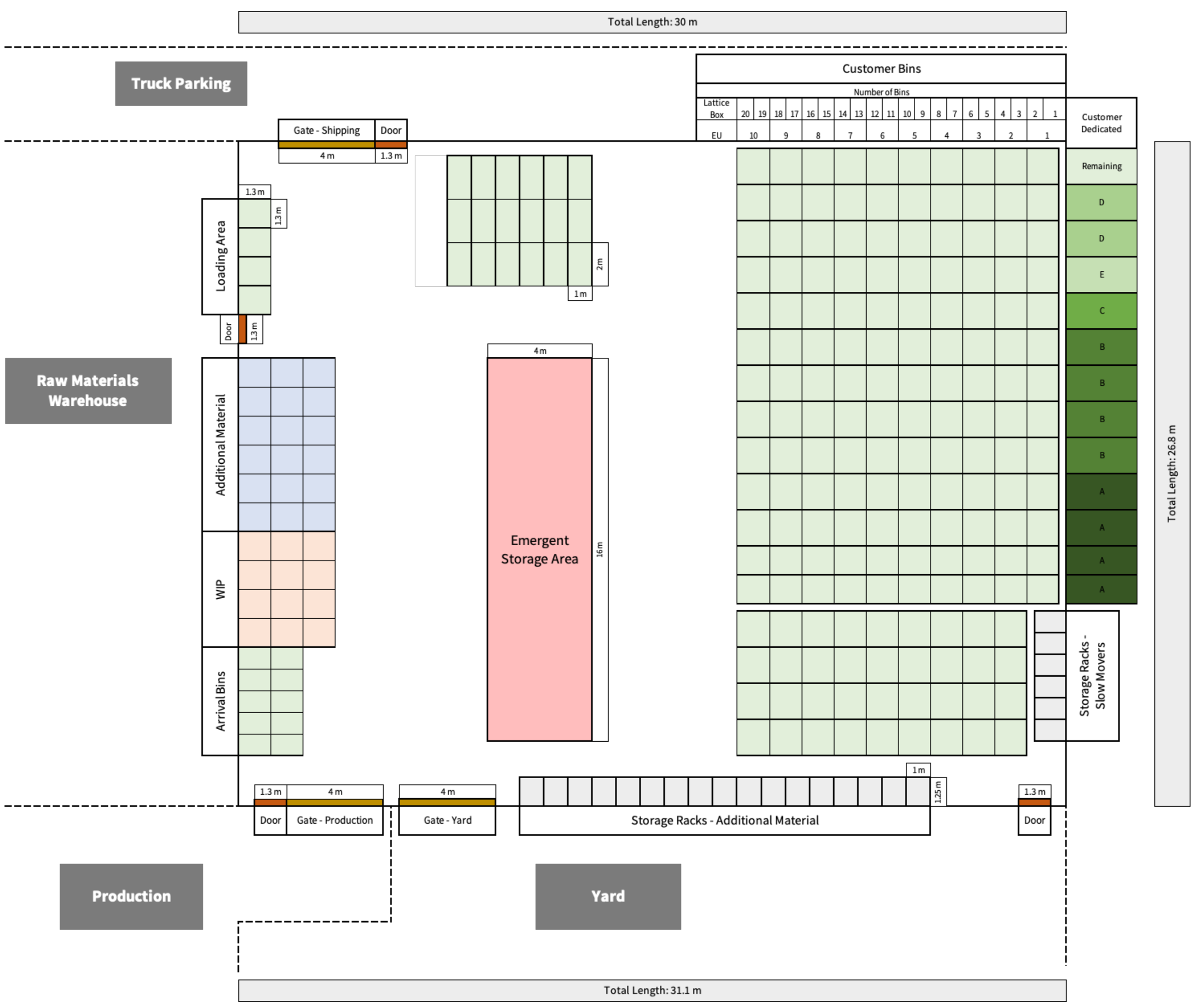

Figure 4.10: Layout of the finished goods warehouse with measurements and entrances.

4.3.1.1 Dimensions

The FGW has a rectangular shape with a total area of 820 m^2. Noticeable is that the upper right corner, in *Figure 4.10*, is not entirely right-angled which leads the right-hand side wall to be slanted. That is, the upper wall is 30 m while the lower is 31.1 m. This is not illustrated in the figure, as the additional 1.1 m is not used in practice. Thus, the applicable area is 805 m^2, with dimensions of 30 x 26.8 m. The usable height in the warehouse is seven meters, since above there are beams that run over most of the warehouse.

4.3.1.2 Storage of SKUs

The storage is a combination of stacked pallets and pallet racks. Most of the pallets are stored stacked. This includes the arrival area, storage bins, loading area as well as areas dedicated to packaging and additional material. These are further described in the text below. There are, however, also pallet racks illustrated as rectangles in the bottom, see *Figure 4.10*, along the middle and to the right, which will be further discussed in *Paragraph 4.3.2.1.*

Arrival Bins
Directly to the left, as seen from the inbound gate from production in *Figure 4.10*, are the arrival bins. These are not explicitly marked but have a sign indicating the size of the area. The arrival bins correspond to five bins, each with a capacity of two pallets in depth, where pallets are stacked three high. Thus, the total capacity is 30 pallets. The bins are shared, but used for one customer at a time, which is decided by the production forklift operators. The arrival bins are rarely used to their full capacity. This is since the pallets are stacked three high before put-away, an operation performed by the warehouse workers.

The time spent in the arrival bins depends on the production- and warehouse workers. On an ordinary day at full capacity without breakdowns the production lines generate approximately 6.6 pallets per hour, equating to pallets arriving in the FGW nine minutes apart, meaning that a three-SKU-stack is ready for put-away every 27th minute. Warehouse workers across both shifts aim to inspect if put-away is needed every hour, although an unloading in the RMW or loading in the FGW can disrupt this. Typically, a warehouse worker checks every hour, and thus pallets are rarely stored in the arrival bin for over an hour.

Storage Bins
The on-floor pallet bins that stretch from the top right downwards are the main storage in the FGW, see *Figure 4.10*. The largest area on the top right-hand side, explicitly the top 13 of them, are ten pallets deep and therefore accommodate a maximum of 30 full EU-pallets in each, assuming that pallets are always stacked three high, which is current practice. Each pallet location has the size of 1.3 x 1.3 m. However, for the smaller lattice boxes, placed with the wide end facing the front, the capacity is doubled. Thus, the capacity of one bin is 30 full size EU-pallets or 60 lattice boxes. Usually, the lattice boxes occupy two or three bins, rarely one or four. Each bin, not every stock location, is demarcated by yellow paint and dedicated to a specific customer, as seen on the right-hand side in the figure.

During the years, with the increase in production volume, four new bins have been added "unofficially". These are not marked out but are used in the same manner as the others. The bottom four bins are approximately nine SKUs deep, to make room for the right-hand side pallet racks and can hold 108 pallets. This aggregates to a capacity of 558 SKUs in total for all the storage bins, assuming three pallets high and two bins dedicated to lattice boxes.

Loading Area

The main loading area, located in the upper middle part of the FGW near the shipping gate and depicted in *Figure 4.10*. The area has its edges outlined with yellow markings, but not marked bins. To allow for *marking*, detailed further in *Subsection 4.2.4*, the pallets are spaced. Each pallet location is approximately 2 x 1 m, in contrast to 1.3 x 1.3 m, providing the shipping coordinators with 0.8 m between rows of EU-pallets. Additionally, due to the limited space, the pallets are placed close together, indicated by 1 m in width, in contrast to 1.3 m in the rest of the FGW. This aggregates to a total capacity of 54 pallet locations.

There is a smaller extra loading area, located in the upper left corner in *Figure 4.10*. These are, like the extra storage bins, not marked and have been added unofficially in practice. The area fits approximately four pallets in width, and 12 pallets in total., assuming three pallets high. However, in practice the area is mainly used for small orders, one or two pallets, and is thus rarely used to its full capacity.

The total capacity of the loading area aggregates to 66 pallet locations, 54 in main and 12 in extra. This is too low as the average number of shipped pallets is 86.6, as shown in *Figure 4.2*. Thus, the current loading area cannot satisfy current needs, which is compensated by using a larger loading area in practice, as illustrated in heatmaps, see *Figure 5.9 and 5.10*.

Additional Material - Production

The bins to the left are divided into sections for different functions. All of these are demarcated by yellow floor markings. The twelve bins are divided into two sections of four and eight pallets respectively. Both these sections, and the six top ones, are for spare parts and customer specific additional material. The material in these bins is later used in production, but not stored in the RMW due to limited capacity. The number of SKUs in this section of the FGW aggregated to 46 pallets, as measured during a deemed representative day.

WIP

The WIP area, situated on the middle-left side and marked orange in *Figure 4.10*, is designated for semi-finished SKUs that have been processed and packaged in the production but require repackaging before shipment. This is mainly for aftermarket customers or by customer request, where the products are packaged one-by-one within the pallets, which is not standard practice. The area has four dedicated but unmarked bins, each estimated at three pallets deep, giving a capacity of 36 pallets. However, the area is seldom fully utilized. Due to the nature of the stored goods, which are to be put back into production for repackaging, the storage area is located relatively close to the production gate. In practice, the area is also used to store pallets with spare parts.

Additional Material
The Additional Material storage area, located in the middle-left side with a blue color in *Figure 4.10*, is used for material used in production. This corresponds to material such as pallet collars and inter-layers. Most of the pallet collars are stored outside in the yard, as described below, but one customer demands the material is stored inside. The interlayers are used for several of the customers and are stored in the additional material storage area. The full area has six dedicated bins, each three pallets in depth, it a maximum capacity of 54 pallets. The area has a high utilization in practice.

Storage Racks
The FGW has two storage racks, located in the lower right corner marked in light grey as seen in *Figure 4.10*. The pallet racks are approximately six meters high, with varying sizes of each level and there are no dedicated locations. The largest of them is used for additional material. This includes material such as empty wooden pallets and paper pallet dividers. These are also used in production but placed in the FGW due to space constraints. The estimated picking frequency is one pallet per day, for the pallets used in production. Additionally, there is another pallet rack used for slow movers. In this storage rack old machine parts, that are not used but too valuable to be thrown away, are stored. This pallet rack is very rarely used, estimated picking frequency is once per quarter. The rack is also inaccessible, as the added customer bins are placed in front of it.

Emergent Storage Area
The FGW features an Emergent Storage Area, located in the middle and marked in red in *Figure 4.10*, used for storing a variety of items. The term "emergent" springs from the fact that the area was unplanned and arose from limited storage capacity. The area, more a flexible space than designated to some type of SKU, is not marked and typically contains a combination of empty wooden pallets, additional material, waste container and other storage items. Only the two waste containers are intended to be stored there, all others are put there due to space shortages. Stray additional material is also stored there. To avoid disrupting operations in production some items from production are at times placed there, often silently to not upset warehouse workers. Thus, some call the area "the junkyard".

The placement of the emergent storage area is not optimal, as it must be rounded to place SKUs stored in the arrival bins into the customer bins. Excluding the non-pallet items the area currently holds the equivalency of approximately 20 pallet locations, as measured during a deemed representative day. However, these include bulkier items that are placed on two joined full sized EU-pallets. Furthermore, it is important to notice that the area varies drastically in size, and consequently the number of SKUs stored.

Yard
The yard, located below the FGW and marked with a dark grey box and checkered lines in *Figure 4.10*, is used for storage of unconventional items. This is mainly empty packaging material, later used in production, that is stored outside year-round and put in the FGW to dry, for at least a couple of hours, before being used in production. However, during peak levels in the FGW, some pallets are stored in the yard during the summer months.

4.3.1.3 Location of Receiving and Shipping

The FGW handles the material flow between the receiving gate from the production, *Gate - Production* in *Figure 4.10*, onto the pallets is loaded onto the truck through the shipping gate, *Gate - Shipping* in the figure. With the main storage bins on the right side, the warehouse is most accurately classified as having a U-flow configuration. The last gate on the figure, which is located to the right of the inbound gate, leads to the yard. The gates themselves are high industrial gates that allow for forklift traffic, also with stacked pallets. Additionally, there are four doors in total, one on each wall. They are indicated by a red color in the figure and used by employees for entrance and exits to the warehouse.

4.3.2 Storage & Handling Equipment

Giving an in-depth account of store and handling equipment, along with the use and integration of technology and workforce management is essential to outline the warehouse design of Alfdex. The following sections describe the specifics of the storage solution of pallet racks, the handling equipment in use, the structure of labor that supports the FGW operations, the absence of automation and the role and delimitations of the current ERP system.

4.3.2.1 Storage Equipment

The storage equipment used in the FGW are storage racks. The single deep pallet racks currently hold a mixture of two different types of material; (i) packaging material and (ii) pallets that are highly unlikely to be needed and moved. The first category is packaging material used in production and the second category entails old machinery or pallets containing articles no longer sold. The racks are six meters high and the number of levels vary between the two setups. The racks on the right-hand wall have seven levels, with a total capacity of 42 pallets, and the racks on the bottom have four levels, with a total capacity of 48 pallets. Altogether that equals 90 pallet positions, of which around 60 SKUs are currently stored.

4.3.2.2 Handling Equipment

Alfdex currently uses one counterbalance truck and two reach trucks as handling equipment in the FGW. The counterbalance truck is by far the most operated and is preferred for picking and loading. The reach trucks are for example used by a second warehouse worker to support the one performing loading by stacking pallets, when truck drivers request deviating pallet stacks. They are also used for the operation of refilling packaging material in the production from the FGW. The counterbalance truck has no notable restrictions for operations, except for the forks being un-extendable which leads to warehouse workers having to drive and retrieve the long forks stored outside of the FGW for some loadings. The simple forklifts are less suitable for picking and loading due to weight and maneuverability. The only hard restriction, however, is that one of them cannot reach the top level of the current racks.

4.3.3 Automation & Information Systems

No form of automation is currently employed in the FGW. The most advanced tool in terms of connectedness are the hand-scanners that are occasionally used by shipping to register pallets for shipping. However, it was mentioned during the display of work completion that those are rarely used due to very marginal gains in terms of time-savings along with frequent disconnections, due to poor connection in the FGW. The FGW should be categorized as a manual warehouse. The categorization is motivated due to the non-existing automation with limited digitization. Thus, the FGW is placed in the lower left of the matrix by Norrman and Kembro (2022) conceptualizing smart warehousing, see *Figure 4.11*.

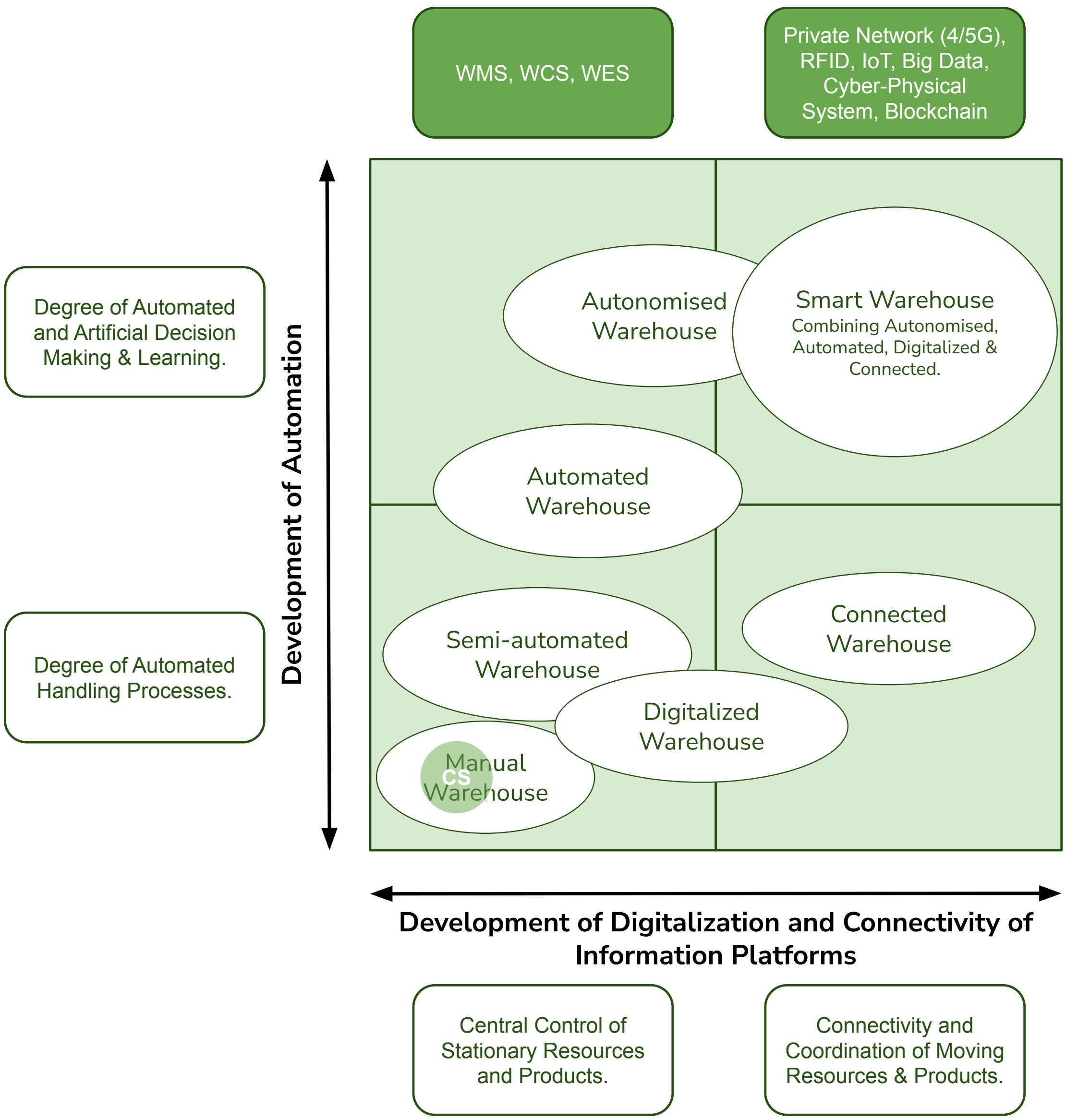

Figure 4.11: Alfdex Current State FGW Placed in the Automation Matrix.

The current information system is limited in its support for the employees operating in the FGW. The company uses an ERP system for tracking the inventory in the FGW. The ERP system treats the whole FGW as one location, independently of which area the SKU is stored.

The ERP system tracks the level for each article but does not consider which pallets enter or leave. Thus, there is no system support to help ensure FIFO. This solely relies on the shipping personnel checking arrival date manually. The location of the SKU is updated after the forklift operator, in the production area, has packaged and weighed the pallet. After the SKU is finished processing, and the location is updated as the FGW, the SKU is placed in the arrival bins in the FGW. Here it is located within the system until the invoice is sent to the customer. This action is done in the afternoon the same day as the SKU is planned to be shipped. Typically, this is after the pallet has been picked up and left the FGW. However, the pallet could still physically be in the FGW but removed from the ERP system, if pick-up is delayed until after the shipping coordinators have left.

In the RMW of the Alfdex facility, the ERP system is used in a more specialized way. There, each SKU has a dedicated pallet position which enables easy locating and retrieval. There, the hand scanners are used throughout put-away and retrieval operations. This implies that the ERP of Alfdex has support for functioning in such a way assuming the required setup is performed.

4.3.4 Labor & Safety

There are currently six employees who are dedicated to operational assignments in the FGW. Four of these are dedicated warehouse workers, working both in the RMW and the FGW. Three of these, whereof one does it for 50% of the workday, works during the morning shift. There is another warehouse worker that works the evening shift. The last two work within shipping and perform mainly administrative tasks during the morning shift. However, they also physically participate in the warehouse operations with picking pallet flags and marking shipment information on the pallets. Additionally there are forklift operators from production that oversee the put-away process to the arrival storage bins. The put-away operations are performed during the morning and evening shift by some of the warehouse workers, when the pallets in the arrival bins have been stacked three pallets high.

4.4 Performance

Alfdex has not implemented the use of Key Performance Indicators in their FGW to measure operational performance in the FGW yet. The absence of KPIs and any other performance measure represents a gap in the management strategy as they are pivotal in controlling and improving efficiency. They are also exceedingly valuable when implementing or proposing changes as they are well chosen and the influence on them will be telling for the value of the improvement. It would also provide Alfdex with a clear set of measures to work with, both internally and externally, and set an agenda for improvement. They also foster enhanced decision-making processes internally and an interest in measuring.

4.5 Employee Problems - Identification

Problems that were identified during the conducted employee interviews yielded the problems and subjective severity presented in *Table 4.2*. Note that some problems were mentioned more than once and that the severity (ranking) is then the average of the observations. Each problem is described in more in-depth in the following sections.

Table 4.2: Problems put forward during interviews and the (interviewee's) estimated severity.

Problem	Average severity (1-7)	# of mentions
Incorrect inventory levels	7	2
Difficulties finding pallets	7	2
Restricted SKU availability	7	2
Incorrect freight document procedure	4	1
Different packaging for articles	3	1
Vulnerable shipping procedure	7	1
Challenging to drive forklift	5.5	2
Disruptive warehouse clutter	6.67	3
Stack-changing upon loading	3	2
Truck arrives one day late	5	1
Uneven surface in FGW	7	2
Poor connection in FGW	1	1
Unfavorable working conditions	7	2
Unexpected staff movement	7	1

Incorrect inventory levels
Incorrect inventory levels lead to several disadvantageous operations for Alfdex. The worst outcomes include poor order-fulfilment or pallet mix-up, resulting in the wrong pallets being sent. It also frequently leads to personnel having to search for and account for pallets. One cause of this issue is unfavorable circumstances of "finishing" pallets in production (which adds them to stock) before the actual pallets are produced, done for efficiency reasons. It also occurs when a pallet is removed for quality testing. Even when products are in stock, incorrect stock levels are problematic, often leading to situations where staff cannot withdraw the articles and must send a request for inventory stock-taking to the shipping coordinators.

Difficulties finding pallets
Troubling conditions for finding pallets means the operation of picking, both *pallet flag picking* and *SKU picking* takes longer than they need to. It may also lead to the wrong pallet flag/pallet getting picked, which disrupts operations upon discovery, or even worse leads to the incorrect SKUs being sent. The difficulties stem from a combination of aspects; SKUs being cramped together on limited space and poor visibility of tags (both due to SKU stacking and sparse lighting).

Restricted SKU availability
The current LIFO-oriented design for pallet storage limits what SKUs are available. It is also unclear what SKUs arrived first as they need to be constantly moved for retrieval of older SKUs, which makes *pallet flag picking* considerably more difficult and time-consuming. Troubles also arise during *picking* where the forklift operator must move SKUs to retrieve others, which is double handling. The problem is caused by the design of pallet storage.

Incorrect freight document procedure
The truck drivers usually sign the freight documents before the pallets have been loaded onto the truck and subsequently forget to check for the right quantity of pallets. Without delving into the question of responsibility this ultimately leads to an order fulfilment error. The reason this occurs is mostly a question of procedure and there should be a standard procedure, in the FGW, for freight document signing and handover.

Different packaging for articles
With the current operations some articles have several ways of being packed according to the wishes of one or several customers. Unfortunately, the supply of lattice boxes is unstable and subject to change, requiring production workers to manually re-log pallets in the system. The implications for freight booking depend on the time of these changes relative to shipping. Errors in re-logging result in inaccuracies in stock levels.

Vulnerable shipping operations
An identified risk within the operations is that the shipping coordinators cannot afford to miss a single day of work. Their roles are highly specialized and none else at the Alfdex can with proficiency perform their work. The tasks have both physical and administrative elements, necessitating their on-site presence. Moreover, the complexity of the tasks means that a temporary replacement would require substantial training before working efficiently in the role. Additionally, the tasks are can be congest upon problems, meaning time management adds another layer of complexity, making it challenging to manage.

Challenging to drive forklift
High stock levels make driving forklifts challenging and add time to every operation. The risk of collision increases which poses a threat to both safety and products and equipment. The problem is said to stem from the warehouse being poorly designed for handling the high number of pallets that normal fluctuations can entail. It is also said to be due to the "unfortunate placement of various materials in the center of the warehouse and the too deep and narrow standard bins.

Disruptive warehouse clutter
With the current state of operations, the production workers put their waste from packaging material pallets, hence both material and pallets, in the center of the FGW. Furthermore, as the warehouse workers are expected to transport these out into the yard, waste and pallets are often put disorderly. Pallets that should be stored in production are also placed there occasionally to free up space. The culminating consequence of all this is a FGW that is more difficult for workers to navigate.

Stack-changing upon loading
Depending on the customer, pallet quantity, and freight company the warehouse worker can be required to deviate from the regular stacking policy and add another pallet. The requirement is occasionally imposed by the truck driver. The result is additional pallet handles during the shipping procedure, which has already been identified as a bottleneck. The speed of driving/loading an unusually high stack is also noticeably slower and the uneven surface outside the shipping gate is felt more, which affects the safety of the forklift driver.

Trucks arrive one day late
Occasionally a truck doesn't show up on its intended day of arrival but the day after. The day-to-day number of shipped pallets already exceeds the capacity of the designated loading area, meaning a delayed order would further put strain on the FGW and can make forklift driving in the FGW distinctly more difficult.

Uneven surface in FGW
Three especially alarming areas are highlighted; two drainage wells, one inside the FGW and one outside, and a notably uneven surface just outside on the side where loading occurs. It is mentioned that the forklift wobbles significantly when driving over each of these and that an accident where pallets are dropped, or the forklift drops over is highly likely. The drainage wells can be handled by reducing forklift speed while the uneven surface just outside needs to be avoided entirely by driving around, which nonetheless costs time. It was also mentioned that between the different parts of the facility i.e. RMW, production and FGW there are thresholds and splices that damages trucks and continuously lead to several breakdowns. These breakdowns could severely affect operations if fewer trucks were available.

Poor connection in FGW
Hand scanners are available for performing some administrative work in the FGW. An observation is however that their efficiency is hindered by poor, and sometimes non-functioning, connection in the FGW. The result is that hand scanners are experienced to substantially increase the time spent on operations, and with only marginal gain.

Unfavorable working conditions
Limited lighting hinders certain operations, especially detail-oriented tasks. Additionally, the warehouse is currently in an uninsulated industrial building, which means more extreme temperatures than outside. Finally, extensive forklift driving on the asphalt floor leads to both discoloration of the floor and very poor air quality, which also leads to the current lack of ventilation in the warehouse. Another disadvantageous circumstance is that indoor trucks from production operate in the FGW where there are both trucks and pallets wet from outdoor use and storage. The concrete floor in production becomes extremely slippery.

Unexpected staff movement
Occasionally people who do not work in the FGW move around without the regulated safety equipment. This affects the operational capacity of the forklift drivers and has also given rise to a feeling of uncertainty about how to handle the situation.

4.6 Company Visits

All visits to external companies were conducted as planned with an initial tour of their warehouse followed by an in-office interview. The visits generally took 2 hours, consisting of one hour for each activity. The general findings defining some contextual factors of the warehouses are summarized in *Table 4.3*.

Table 4.3: General information on visited companies.

Context	Company A	Company B	Company C	Alfdex
Company-type	Trading	Production	Production	Production
SKU-types	EU-pallets & boxes	EU-pallets	EU-pallets	EU-pallets & lattice boxes
Pallet positions (main+loading)	9500	150 + 144	300 + 100	453 + 72
Pallets/day	150	140	60	85
Warehouse dimensions	8500 m^2	150 m^2	225 m^2	930 m^2
Truck types	Counterbalance, reach & turret	AGVs & counterbalance	Counterbalance & pallet jacks	Counterbalance & pallet jacks

4.6.1 Company A

Company A's warehouse is a recently established facility, designed and built purposefully, that commenced operations in 2021 serving as a replacement for the prior warehouse. The warehouse predominantly utilizes pallet racks for storage and houses a diverse inventory of 550 different articles, highlighting its capacity for managing a broad range of products. The company's customer base is primarily comprised of business-to-business (B2B) clients and engagements with smaller entities, including one-person enterprises, reflecting flexibility. The company employed a dual strategy for order picking, accommodating both full pallets and mixed-article orders. Roughly 50% of the orders involved complete pallet selections, while the remaining 50% consisted of assortments of various articles.

The warehouse utilizes several types of storage equipment and is divided into seven different parts: (i) wide aisle single deep pallet racks, (ii) narrow aisle single deep pallet racks, (iii) multiple deep flow racks, (iv) floor storage, (v) "picking market" (fast floor-picking of smaller items), and (vi) area for incoming and outgoing pallets. The wide aisle pallet racks with dedicated storage and a capacity of 2700 pallets enable efficient picking. The narrow aisles pallet racks are considerably smaller but space efficient, capacity of 4500 pallets, using shared storage suitable as a buffer for slow-moving goods. The multiple deep flow racks, with several levels, are located near incoming and outgoing. Thus ideal for fast-moving full pallets and ensures FIFO, important as an order must contain same-batch articles. The floor storage was space-efficient and used for large pallets. These refilled the "picking market", consisting of pallets in marked floor bins for easy picking of cartons. The area is dedicated to incoming and outgoing pallets, featuring marked floor bins adjacent to terminals.

The warehouse utilizes different types of handling equipment for different operations. The most common is the counterweight truck used for the wide aisles, flow racks, floor storage, picking market, and incoming and outgoing. Of the seven counterbalance trucks, five are ”ordinary” and used in all the aforementioned operations. Additionally, there is one adapted for outdoor driving and one suitable for lifting containers in the incoming/outgoing area. There is one reach truck used for levels five to seven in the wide aisles, whereas the counterbalance trucks are used for levels one to four. Lastly, there is a semi-automated turret truck used in the narrow aisles. The turret truck is guided by a rail in the ground to ensure safe driving.

4.6.2 Company B

Company B has an FGW with only 294 pallet positions, which is low considering a daily flow of 140 pallets. The physical layout is structured with the entrance and shipping area located on opposite sides. The strategy of only holding the next one and a half days of orders as inventory, a major reason for the low number of pallet positions, defined the warehouse. Their strategy reflected a lean inventory strategy aimed at reducing holding costs.

The warehouse's storage system is a mix of flow pallet racks in the FGW area and designated storage bins near the shipping area. Flow racks, of the gravity-assisted kind, improve handling efficiency, ensure FIFO as well as allow for handling by AGVs. The flow racks truncated the distance between production and FGW. The bins, where pallets were stored by order, utilized a shared storage policy and could manage a total of 150 pallets.

The shipping area was divided into four zones with direct access to their gate, each zone having a capacity of 36 pallets. A recent investigation of having flow racks in the shipping area, to reduce travel distance, showed that limited height near the gates in addition to the slanting of the racks requiring more height rendered them unsuitable, with lost pallet positions as a consequence. The warehouse manager also pointed out the investigation of other racks as flow racks can be outperformed by high pallet racks in terms of space utilization.

Company B has three AGVs, with two actively transporting pallets from production to the racks and three warehouse workers. The warehouse manager emphasized the precision of the AGVs, making them suitable for put-away assuming the pallets' position before retrieval is precise. Flow racks provide the required precision to serve as a great interface between automated put-away equipment and human pickers. The warehouse team consisted of two workers on alternate shifts picking and a third solely loading trucks. All used counterbalance trucks. The two were also responsible for the put-away of pallets that had diverging measurements and were finished by robotics located in direct connection to the FGW.

The AGVs were introduced between 2018 and 2019 as a part of a strategic initiative to reduce operational costs. During implementation, the warehouse was modified with sensors on the push-back racks and a separate system that could interface with both WMS and sensors. The current WMS requires the scanning of pallets at every stage of storage and handling, which ensures a high level of delivery precision. Although it effectively eliminates the risk of dispatching incorrect orders, it is notably time-consuming.

Company B evaluates its FGW performance based on delivery precision and the monthly financial value of inventory. The KPI of utmost importance, that originates from a lean mindset, is the "Zero value," a metric that assesses stock levels in relation to the fulfillment of the next one and a half days' orders. This KPI reflects the company's ability to meet customer demands without overburdening its storage capacity.

4.6.3 Company C

Company C is a production company selling to other companies (B2B). The visit was conducted at one of their production facilities, specifically investigating the FGW. The products are explicitly shipped in EU-pallets, both regular size and half as well as differing in the number of collars ranging from one to eight. The sold products were all MTO and customized.

The FGW features a rectangular room, about 15 x 15 m, with a ceiling height around 6 m. Storage spots comprised single-deep pallet racks with varying heights per level to suit the SKUs' different heights, influenced by the collar count. Consequently, rack heights ranged from five to eight levels. Inbound and outbound areas were closely positioned, with outbound to the immediate right from the entrance, creating a U-flow layout. The racks had a capacity of 300 pallets. Outgoing pallets, prepared and placed on the same day for shipping, were either stored in the terminal or another site. The terminal, a smaller space of roughly 5 x 5 meters, accommodated some outgoing pallets. However, due to limited terminal space versus daily flow, some pallets were stored in a nearby tent. This tent, adjacent to the FGW, served as a mixed storage area for both incoming and outgoing items, addressing capacity challenges. Therefore, the exact capacity of the loading zone is undetermined, as the tent's pallet count varied, but overall estimated at 100 pallets.

The warehouse operations were performed by different handling equipment and personnel. They were performed by a team of six truck drivers, working with both inbound and outbound traffic. When a pallet was finished in the production the pallets were directly placed on an available location in the pallet rack, the exact location is determined by the driver. The picking is dependent on the picking list and is not picked in any specific order. The handling equipment used in these operations are primarily pallet jacks, both standing and sitting. However, counterbalance trucks are also used, primarily in the loading procedure.

5 ANALYSIS

This section aims to divulge the findings that were attained through analysis of the data. In accordance with the hitherto used contingency approach the analysis of the contextual factors will be looked at first followed by a more in-depth look of the warehouse operations and then the warehouse design & resources. The analysis of the alluded to problems comes after. The final part concludes what insights were gained from the company visits. Summarizing, the section follows the structure: contextual factors, warehouse operations, warehouse design & resources, problem evaluation and finally company visit insights.

5.1 Contextual Factors

The analysis of contextual factors looks at stored SKUs in FGW, main storage and loading area respectively. Activity profiling is also applied on sales and shipment data.

5.1.1 Stored SKUs

Loading Area
The average number of SKUs in the loading area per day and customer is shown in *Figure 5.1*, expanding on *Figure 4.2*. The figure clearly illustrates how the number and characteristic of SKUs in the loading area change throughout the week. The data is also divided between customers, using the same color scheme as in *Figures 4.7 and 4.8*. The days with the most SKUs are Tuesdays and Thursdays, which are the main shipping days for *Customer A*, and additionally, *Customer E* only ships on Tuesdays. The remaining days have shipping to *Customer B & C*, with volumes increasing throughout the week. *Customer C* ships on both Tuesday and Friday. Due to the significant variance in volume and customer requirements between days, the loading area needs to be flexible.

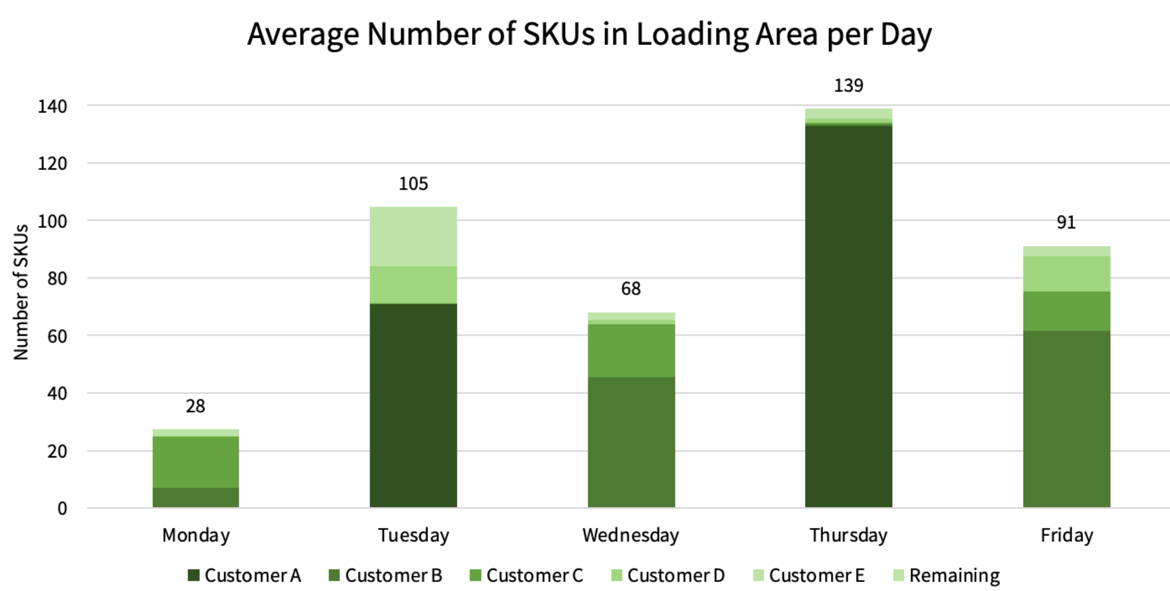

Figure 5.1: SKUs in Loading Area for each weekday, during fall of 2023.

FGW

The number of SKUs in the different parts of the FGW parts, by weekday and month, is illustrated in *Figure 5.2*. In these graphs, SKUs are separated between the loading area and the main stock, consisting of customer bins as described in *Subsection 4.3.1*. The left figure shows that the number of SKUs in storage is higher on Mondays and Wednesdays, and in the staging area during the following day. From the right figure, it can be concluded that there are some discrepancies between months. There is a clear upward trend for the stock levels towards December, which is explained by the building inventory towards the holiday season. This fact is interesting to note, as the FGW aims to keep an even stock level throughout the year, but in the there is large differences. The seasonality has to be accounted for in terms of maximum capacity for the new configuration.

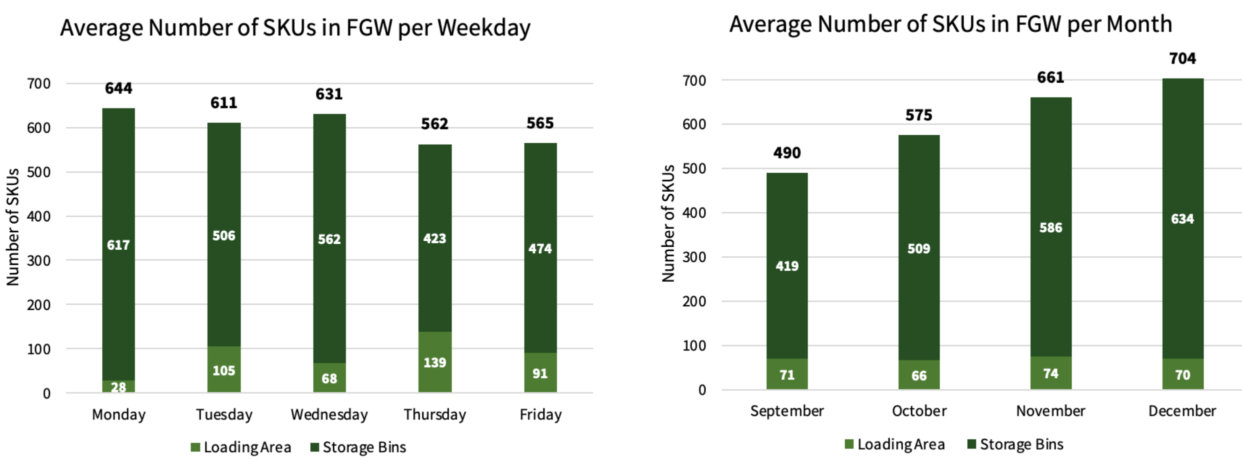

Figure 5.2: SKUs in FGW per weekday, left, and month, eight, during all of 2023.

The shipment characteristics, in terms of number of SKUs per shipment and number of shipments for each article number, are illustrated in *Figure 5.3*. The results illustrate the average number of SKUs per shipment. This number is important as it impact the operations for the article. If the article is shipped three or more SKUs at a time, they are more effectively handled as stacks, since the stacking policy is three high. The figure also illustrated the number of shipments of each article, which illustrates the frequency of shipments. To conclude, all articles with an average number of SKUs per shipment above four, indicated by the *Stacking Limit line* in *Figure 5.3*, should be handled as stacks in the FGW. There are 24 articles above the stacking limit corresponding to 89.5% of the volume, as of sales during 2023. Hence, they will on average, with an average number of finished goods SKUs of 360, be 322 SKUs stacked and 38 SKUs to be handled individually.

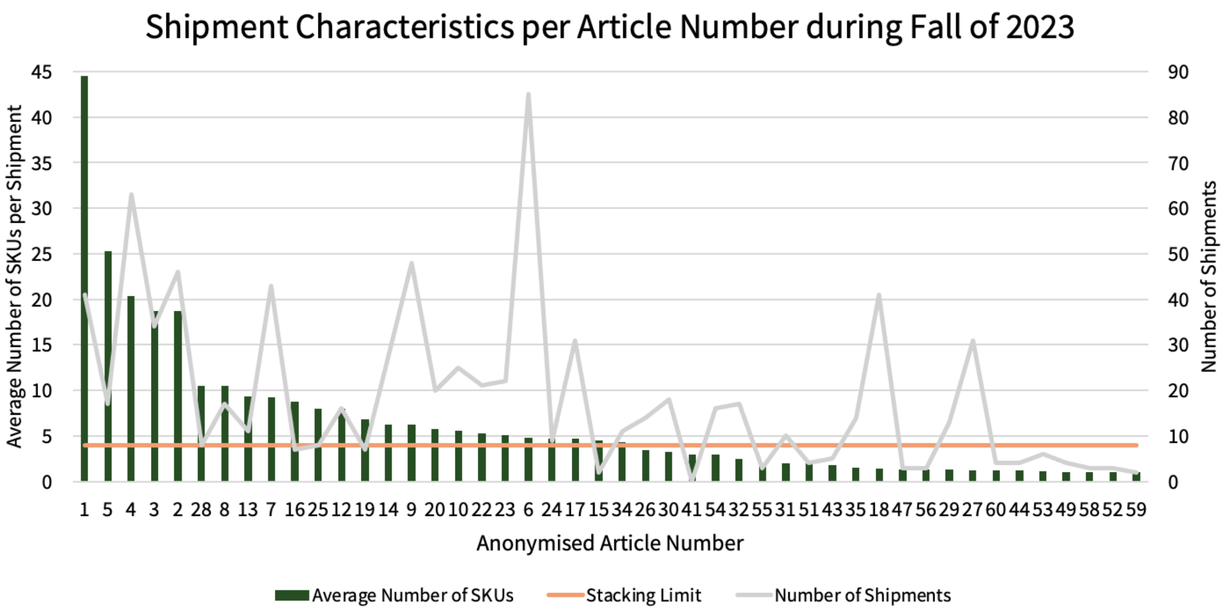

Figure 5.3: Shipment Characteristics during Sample Period, fall of 2023.

5.1.2 Activity Profiling

In this section of the report the activity profiling tools are used to illustrate the current state of the FGW. The ABC analysis is presented in the first paragraph followed by a Heatmap in the second.

5.1.2.1 ABC-Analysis

The ABC-analysis was done using the data for number of sold SKUs during 2023. The analysis was conducted to analyze, and visualize, the distribution of the sales data. The analysis serves as a basis to make an informed decision about configuration elements, mainly the storage policy, which is heavily influenced by the demand distribution. The analysis was conducted from two different perspectives: per customer and article.

The first analysis, investigating SKU sales per customer, is illustrated in *Figure 5.4*. From the figures the demand distribution for customers has a clear Pareto-distribution. The analysis is conducted using an ABC-classification of 80%/10%/10%. This corresponds to *Customer A* and *B*, cumulatively 74.2%, is classified as A, *Customer C*, cumulatively 86%, is classified as B and *Customer D, E* and *Remaining* is classified as C. Thus, from this analysis different customers should be handled differently, since a minority of the customers constitute most of the SKUs stored and handled in the FGW.

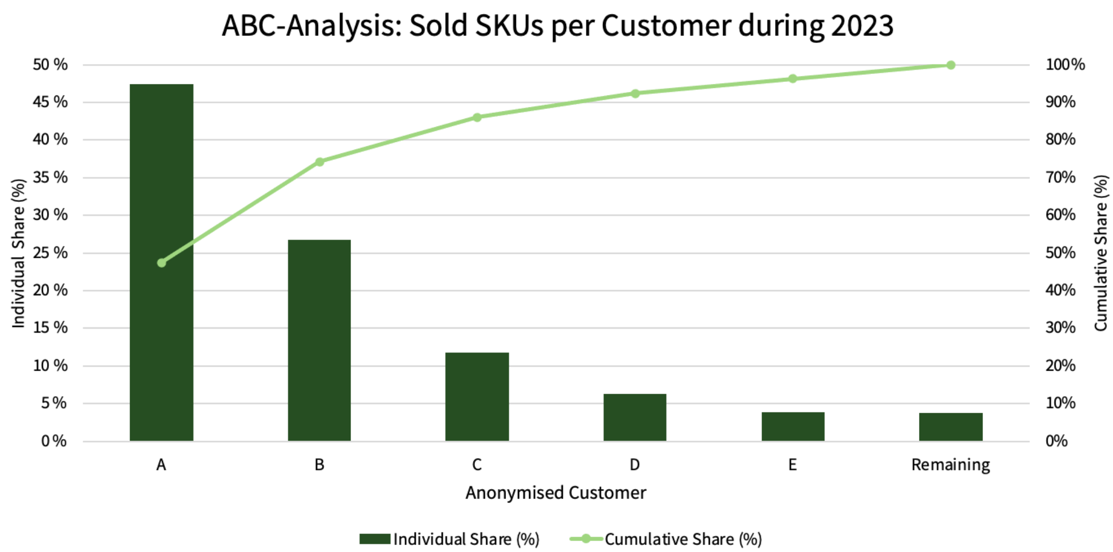

Figure 5.4: ABC-analysis of customers, for number of SKUs sold during 2023.

The second analysis investigates SKU sales per article and is illustrated in *Figure 5.5*. It is clear from the figure that the sales of SKUs per article are heavily Pareto-distributed. Using the previously mentioned ABC-classification this corresponds to *Articles 1 - 11*, cumulatively 78.64 %, is classified as A, *Articles 12 - 21*, cumulatively 89.9%, is classified as B and *Articles 22 - 74*, is classified as C. This analysis also implies that the storage policy should be adapted to suit the most sold articles, as a large proportion of the articles are sold in small quantities.

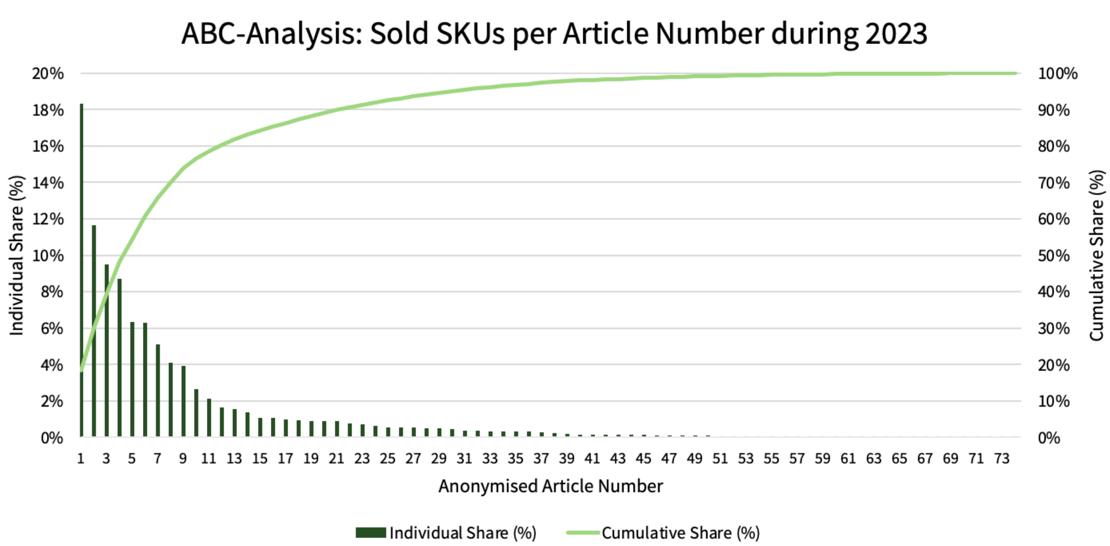

Figure 5.5: ABC-analysis of articles, for number of SKUs sold during 2023.

5.2 Warehouse Operations

The FGW operations have been investigated using a Value Stream Map. The VSM illustrates all operations, with corresponding metrics, within the FGW. Additionally, it presents the information flow, handling equipment and operators involved in operations. The resulting VSM is illustrated in *Figure 5.6*. The times in the VSM is a combination of the measurements for travel distances, see *Subsection 4.2.6*, and pick-waves, see *Subsections 5.2.1* and *5.2.2* below.

The VSM, see *Figure 5.6*, illustrates the arbitrary level of the information flow within the FGW operations. The process is heavily reliant on heuristics, rules, and manual or email communication. The receiving operation takes place after visual inspection when a pallet is done in production. The same is true for the put-away process, when pallets are stacked three high, or a production batch is finished, in the arrival bins. The same principle applies to the following operations. The picking of pallet flags is not based on a picklist from the ERP system, but an email containing the shipping plan from the production planner. The same email is converted into a loading plan, describing what SKUs to pick, mark, and load. These often overlap, if there has not been a change from the morning, when the shipping plan is sent, to the afternoon, when the loading plan is sent. The arbitrary level is present in the picking of SKUs as well. In this process, the lack of a pallet flag, on the side of the SKU, is the guide for picking. To see the absence of a pallet flag, in a poorly lit warehouse with narrowly placed customer bins with SKUs sometimes stacked four high, can be challenging.

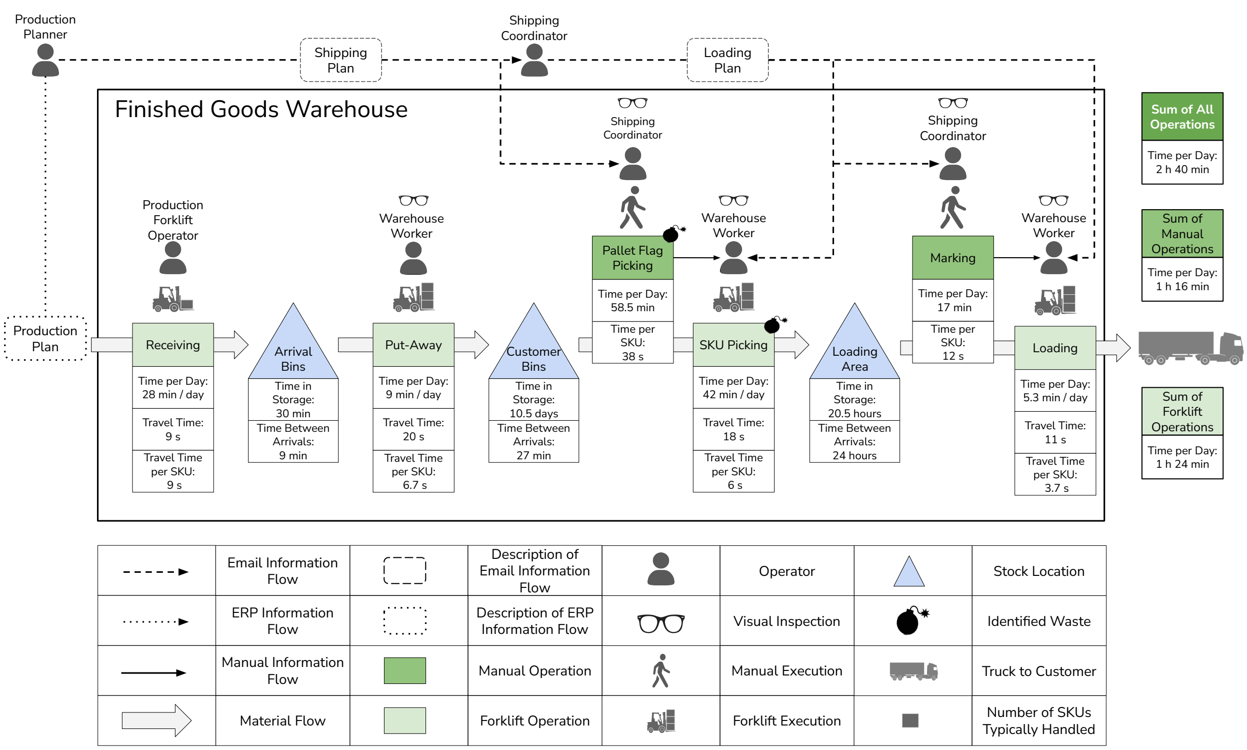

Figure 5.6: Value Stream Map of Current State.

The effectiveness of handling stacks of SKUs in operations is presented in the VSM. In the processes where several SKUs are typically handled at once, that is the put-away, SKU picking, and loading process, the travel time per SKU is very low. Thus, handling several SKUs at once is very efficient and minimizes the number of operations needed per day. There is of course a trade-off between efficiency and safety as well as speed. However, from the interviews with the warehouse workers it has been noted that handling several SKUs at once has not led to any accidents. Furthermore, in our observations, no significant difference in time between handling single or multiple SKUs at once has been identified. Hence, the proposed solution should, when possible, handle several SKUs at once when possible.

The main contribution of the VSM is to identify wastes occurring in the pallet flag and SKU picking operations, marked by the bomb icon. By analyzing the time spent per day these operations stand out. To streamline operations, these operations have to be more efficient.

5.2.1 Picking of Pallet Flags

The operational time for each SKU, measured for both *Pallet Flag* and *SKU Picking* was measured for all pick waves over one week, between 2024-03-05 to 2024-03-11. During the sample period, the average stock level in the FGW reached 308 pallets, corresponding to 69% compared to average levels for fall of 2023. For the number of shipped pallets, the average of the sample period was 81 SKUs, corresponding to 93% compared to the average levels for the fall of 2023. The relatively low number in total stock was due to production recovering from a period of quality issues. Aside from the lesser volume in the FGW, affecting the measurements, the operations and composition of SKUs were deemed representative. Thus, the picking time must be seen as a best-case scenario, since if the average stock level were higher, it would be harder to find and pick the pallet flags and SKUs.

The quality issues of the sample period affect the measured times for the pallet flag picking. During the period, only 61% of the pallet flags were picked during the pick waves. The rest were picked, and not measured, continuously during the day, or the next. The average aggregated time for the pick-waves during the sample period was 35.5 minutes. By compensating for the missing SKUs, assuming all SKUs were to be ready to be picked, this would correspond to 58.5 minutes each day. The measurements only included the active searching for, and picking of, the pallets. This excluded the time spent preparing, such as calculating the number of pallets to be picked, investigating, and writing down the number of pallets in the FGW from the ERP system of each article to be picked. To conclude, the pallet-picking process takes 38 seconds per SKU and approximately one hour on an ordinary day.

5.2.2 Picking of SKUs

The picking of SKUs has been analyzed in three ways. First, a description of the picking times, for the same measurement period as for pallet flag picking, see *Subsection 5.2.1*. Secondly, a lean analysis of the picking times. Lastly, a Spaghetti Diagram of a pick-wave.

Picking Times

The picking of SKUs was also affected by the low stock levels of the sample period. Finding the pallets to be picked without pallet flags is difficult without system support. Thus, when there are more pallets in the customer bins, it is harder to find the pallets to be picked. From measuring the complete pick-waves for the sample period the average time per SKU was 11 seconds. This includes the time to search, move, pick, and transport all SKUs. Each pick often includes picking several SKUs at once, most commonly three at a time and sometimes six at a time for lattice boxes. During the sample week, an average of 89% of the pallets that were shipped the next day were picked in the pick-wave. The aggregated average time spent per day was 37 minutes per day. Compensating for the unfinished SKUs, assuming all SKUs require pallet flag picking, this corresponds to 42 minutes per day.

Spaghetti Diagram of Pick-Wave

The picking process of the Thursday in the pick-wave during the measuring week was selected to be used for creating the Spaghetti Diagram. The full procedure is shown in *Figure 5.7*, based on the layout in *Figure 4.10*. Every line has a circle as the endpoint to denote start and finish. As a side note, it is important to note that the Spaghetti Diagram does not account for driving without pallets, which is necessary but non-value-adding transportation.

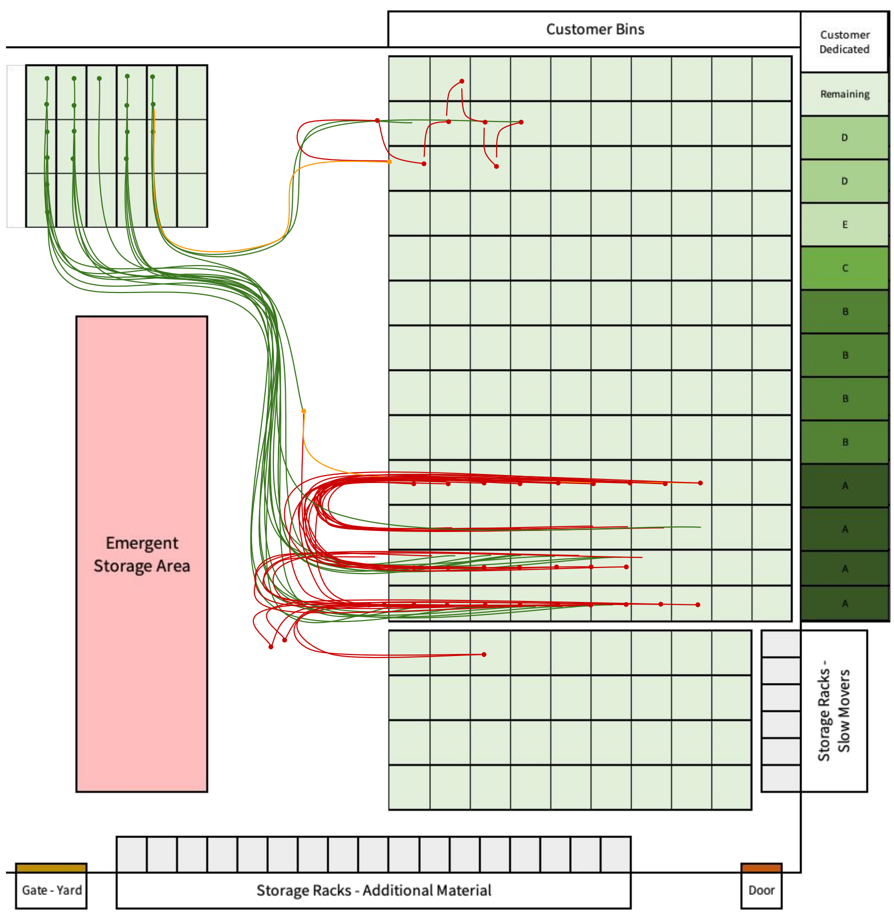

Figure 5.7: Spaghetti diagram showcasing every pick in the picking process of *2024-03-08*.

Lean Analysis of Picking Times
All lifts in a pick-wave can also be assessed using lean terminology. The result is illustrated in *Figure 5.8*. The figure illustrates the pick-wave from the Spaghetti Diagram, see *Figure 5.7*, and uses the same color scheme. A lift is classified as *NNVA - To Loading Area* if the lifted SKUs are placed in the loading area (44%) or *NNVA - Restacking* if it means re-stacking of a SKU that is later placed in the loading area (11%). All other lifts are classified as waste (44%), or NVA. These lifts primarily included temporarily storing pallets somewhere, to reach pallets originally stored behind them. Lifting re-stacked pallets that were not placed in loading was classified as waste.

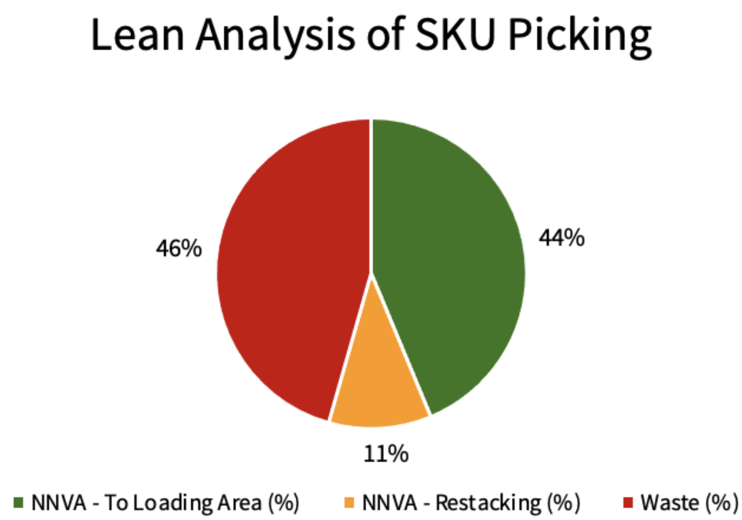

Figure 5.8: Lean Analysis of SKU Picking during the sample period.

The SKU-picking operation is inefficient, as shown in *Figure 5.8*. Almost half of the lifts, hence half of the time spent during the pick-wave, is spent on pure waste. This is an effect of the current floor stacking in the customer bins. Converting the waste percentage into time, means that almost 17 minutes of a pick-wave is waste. By compensating for the lower number of SKUs handled, the average number of 20 minutes per day picking SKUs could be avoided.

5.3 Warehouse Design & Resources

The Heat Maps were made to illustrate how SKUs are stored in the FGW on an ordinary day. The Heat Maps illustrates a snapshot picture of how the FGW looks on an ordinary Wednesday, see *Figure 5.9*, and Thursday, see *Figure 5.10*. The data was collected at 16:00 when all of the shipments had gone for the day. The figures are based on the warehouse layout, see *Figure 4.10*, using the earlier used color scheme for each customer, see *Figure 4.7*. During the sample days, the total number of SKUs in the FGW corresponds to 80%, for Wednesday, and 79%, for Thursday, compared to the average level. Thus, the customer bins and loading area ordinarily have more SKUs than is illustrated in the figures. However, the main conclusions to be drawn can be presented effectively with the chosen sample period, which is presented in the text below.

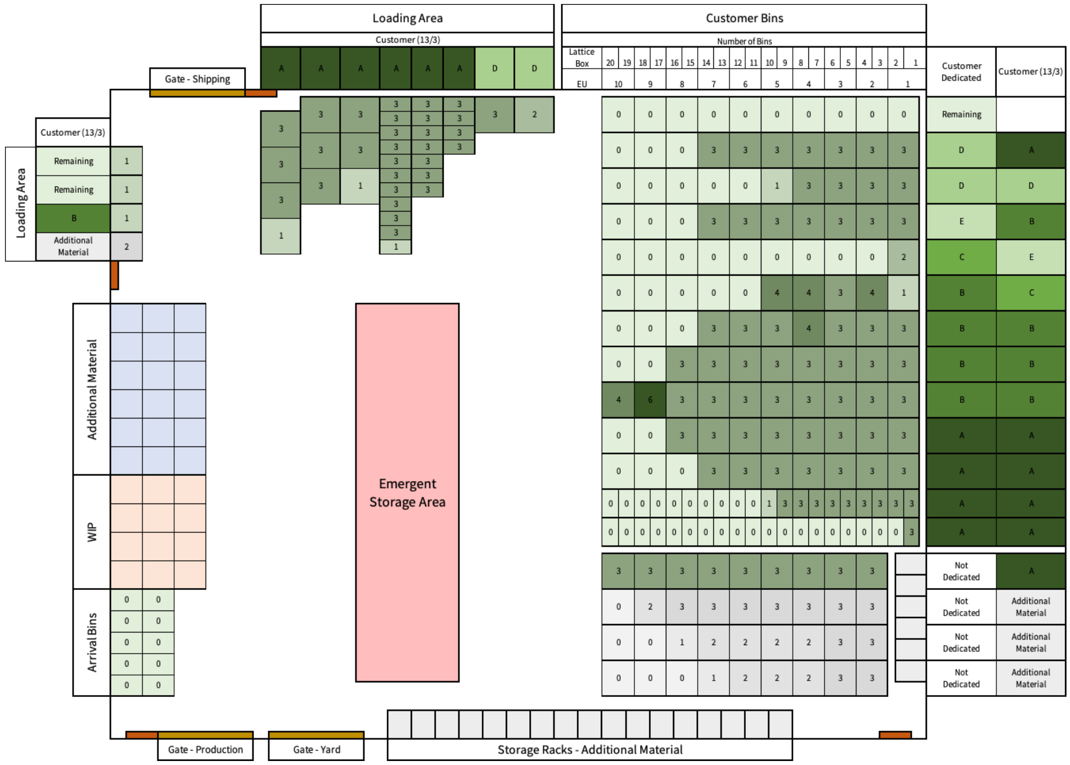

Figure 5.9: Heat Map of finished SKUs in the FGW during Wednesday 2024-03-13 16:00.

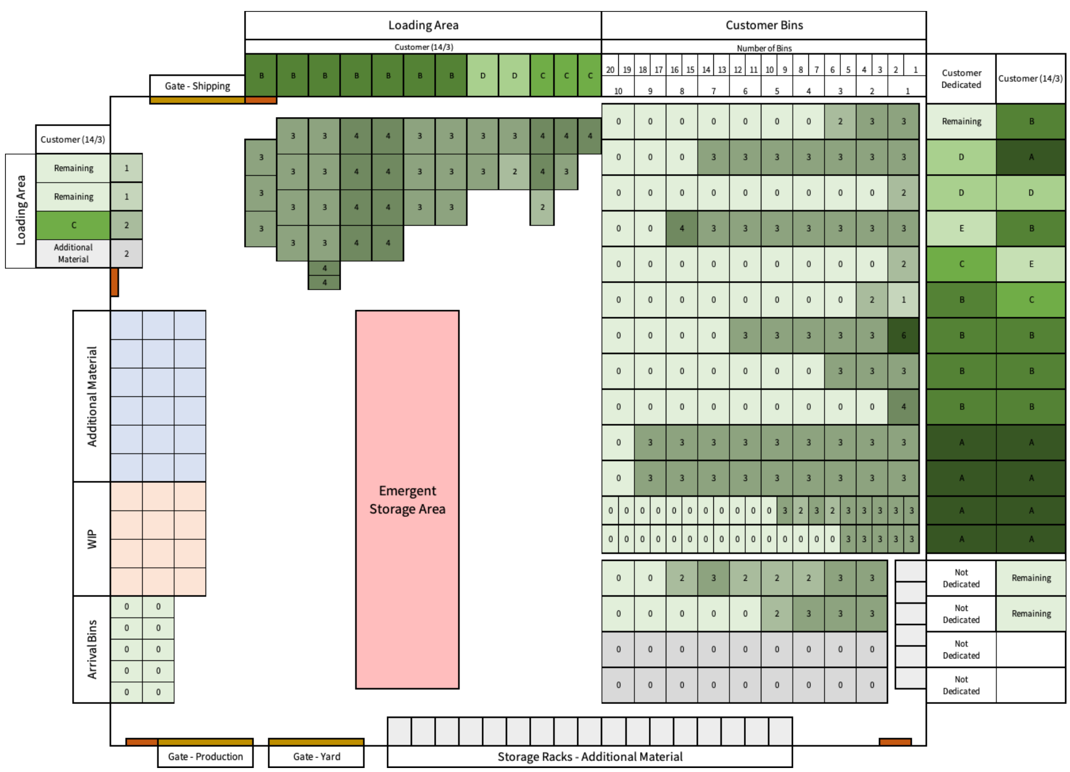

Figure 5.10: Heat Map of finished SKUs in the FGW during Thursday 2024-03-14 16:00.

The Heat Maps highlight the impact of shipping on the composition and utilization of the FGW between days. This is primarily due to the larger customers having dedicated shipping days. Additionally, there are relatively few customers being shipped to each day, but each shipment consists of notable quantities. Thus, as illustrated in *Figures 5.9* and *5.9*, the number of SKUs in *Customer B*'s bins is substantially lower on Thursdays than Wednesdays. This is due to Friday being the primary, in terms of volume, shipping day for *Customer B*. The SKUs are consequently placed in the loading area on Thursday afternoon. This also affects the type of SKUs that are stored in the warehouse, as each customer has a unique demand for SKU types. This further accentuates the need for flexibility in the loading area.

The Heat Maps illustrate the discrepancy between the initial design and the operations in practice for the customer bins. The effect is visible in two aspects, the customer bins and the stacking. The labeling of customer bins is in some respects outdated. That is especially apparent for the first customer bin, which is dedicated to one of the *Remaining* customers. The customer has been a significant customer historically, but no longer. Thus, the bin is used for all customers. Other customers, primarily *Customer A* and *B*, have outgrown their dedicated bins. This is illustrated in *Figure 5.9* and *5.10*, where *Customer A* and *B* are using an extra bin during both days.

A conclusion from the figures is that the dedicated bins are not adhered to in practice; SKUs are roughly placed in customer-designated bins and distinguished by SKU type and pallet flags. While currently manageable due to experienced warehouse workers, it could become problematic during vacation periods or peak load when temporarily contracted warehouse workers have to struggle with the complicated and informal process. Additionally, there is a risk if a current warehouse worker decides to leave. The same phenomenon applies to stacking where sometimes three pallets are stored in the same location, often half pallets stacked on full pallets. It is an unstructured process that requires good judgment of the warehouse workers. Alfdex utilizes that it is a small business with close contact between shipping coordinators and warehouse workers to create awareness of deviating SKU storage.

The Heat Maps also illustrate the utilization of the FGW, for both the customer bins and the staging area. The customer bins are utilized to 53.7%, on the Wednesday, and 43.1%, on the Thursday, counting the bins used for finished SKUs and excluding additional material pallets. Thus, the capacity in the customer bins is relatively low, which is dependent on the stock level corresponding to 80% of the average level. However, even with reasonable utilization, there are issues with double handling.

The figures show that the designated loading area is fiercely undersized. The utilization is 152%, on the Wednesday, and 195%, on the Thursday, of the designated and marked loading area, as illustrated in *Figure 4.10*. In practice, the area between the shipping gate and the customer bins is used when required, as illustrated in the Heat Maps. This implies that on days with large shipping volumes, primarily Thursdays and Fridays, the loading area has spillover effects on other parts of the FGW. On days where the truck arrives one day late, or the volume is exceptionally high, the customer bins must be used. This impairs operations as driving in the FGW is made more difficult by impediments.

5.4 Problem Evaluation

The subsequent analysis utilizes a modified Muda matrix to systematically break down the problems identified during the employee interviews, see *Table 5.1.* The three most critical ones will be of special focus in the ensuing design process, which ensures that focus is directed to the most critical areas.

Table 5.1: Muda Matrix evaluating waste

Problem	**Waiting**	**Transport-ation**	**Unnecessary inventory**	**Unnecessary motions**	**Cumulative score**
Disruptive warehouse clutter	1	7	6	7	21
Restricted SKU availability	2	7	0	7	16
Challenging to drive forklift	1	7	0	7	15
Difficulties finding pallets	6	0	2	4	12
Incorrect inventory levels	6	0	1	4	11
Truck arrives one day late	3	1	5	2	11
Different packaging for articles	1	4	1	3	9
Stack-changing upon loading	0	3	0	3	6
Incorrect freight document procedure	1	2	0	2	5
Uneven surface in FGW	1	1	0	2	4
Vulnerable shipping procedure	1	0	0	2	3
Poor connection in FGW	1	0	0	1	2
Unexpected staff movement	0	1	0	1	2
Unfavorable working conditions	0	0	0	1	1

The three most prominent problems from the Muda matrix are *disruptive warehouse clutter*, *restricted SKU availability*, and *challenging to drive forklift.*

Outside the scope of the Muda Matrix, which targets waste evaluation, comes the analysis of these problems in terms of *safety* and *working environment*. This perspective does not have a direct impact on performance to such a degree that it should be considered actively in the earlier steps of the design process, see *Figure 2.10*, but is still relevant to the thesis. The analysis is conducted similarly to the standard application of the Muda Matrix but where the judged categories are instead *safety* and *working environment*, see *Figure 5.2*.

Table 5.2: Muda Matrix evaluating the problem impact on *Safety and Working Environment*

Problem	**Safety**	**Working environment**	**Cumulative score**
Uneven surface in FGW	7	7	14
unfavorable working conditions	6	7	13
Unexpected staff movement	6	3	9
Disruptive warehouse clutter	3	5	8
Challenging to drive forklift	4	3	7
Restricted SKU availability	3	2	5
Stack-changing upon loading	3	0	3
Difficulties finding pallets	0	2	2
Truck arrives one day late	0	2	2
Poor connection in FGW	0	2	2
Incorrect inventory levels	0	1	1
Vulnerable shipping procedure	0	1	1
Incorrect freight document procedure	0	1	1
Different packaging for articles	1	0	1

The most urgent problem from the matrix above is the *uneven surface*, closely followed by *unfavorable working conditions* and *unexpected staff movement*. This provides a different perspective from the initial Muda Matrix where they were not as distinctly ranked.

5.5 Company Visits Insights

Insights from the company visits are presented below and summarized in *Table 5.3*.

5.5.1 Company A

Insight 1: Optimize for situation
They use a specific combination of resources, with forklifts and aisles specifically tailored to the configuration, for example choosing four-meter-wide aisles, wider than standard, to ensure safety and easy access, or investigating high reach for all counterbalance trucks but deciding to opt for standard models. Using standard models is cheaper and decreases the risk upon breakdowns, as they are more easily replaced or repaired during a leasing contract.

Insight 2: Vertical classification
The largest part of the FGW was the wide aisle single-deep pallet racks, where different vertical levels were classified and utilized distinctly. This affected both storage policy and forklift selection. The first two levels were designated for picking, while levels three and four were used for replenishment of the first two. The top three levels served as a buffer for slow-moving items. Vertical classification meant convenient locations for fast-moving goods.

Insight 3: Stepwise implementation
Company A introduced semi-automated narrow-aisle trucks as an initial phase in their automation journey, aiming for full AGV automation. Full AGV automation requires significant investments in forklifts and information systems. The stepwise approach allows constant next-step evaluation. Consequently, the current operations and setup are deemed adequate and will be kept pro tem. Partially due to the existing contract with the truck provider.

Insight 4: Utilize the knowledge of the operators
The operations manager was new at the job and had not worked with or studied logistics or warehousing before. When promoted one of the first activities he did was to follow the forklift operators. By seeing the operations through their lenses, and discussing improvements, valuable lessons were learned. Thus, the operations manager emphasized that by learning from the warehouse workers directly important insights can be generated.

5.5.2 Company B

Insight 5: Flexibility of AGVs
The AGVs had notable flexibility and wide-ranging applicability. Impressively, the AGVs functioned well and seamlessly integrated into an environment consisting of both warehouse workers and ordinary trucks. Additionally, they demonstrated remarkable capability by being able to efficiently put-away and pick items from slanted pallet racks, showcasing their adaptability and operational efficiency in dynamic warehouse settings.

Insight 6: delimitations of AGVs
AGVs also have delimitations. One such is the need to simplify and detail the material flow for AGV instructing, which limits them to certain operations. The challenges are that AGVs cannot determine if pallets are faulty, nor can they ignore a wooden shard from a pallet and resist stopping. They also experienced issues with inexplicably stopping, which was currently under investigation, and would then require a manual restart to function again.

Insight 7: Implementation of AGVs
AGVs had successively been enrolled in different material flows and implementation often experienced the same challenges. Employees who have no history of working with AGVs were often concerned, often with collisions, necessitating the need for clear information and instructions. Hence the AGVs had successfully run at a 10-15% reduced speed for an initial period to allow for adaptation. Employee concerns generally dissipate.

Insight 8: Material properties negative impact when using flow racks
The material properties negatively impacted the use of flow racks, manifesting in two issues; (i) slanted cardboard pallets and (ii) shards from wooden pallets. Cardboard pallets, placed on top of EU pallets, become slanted over time when placed in flow racks. This is due to gravity affecting the articles inside in combination with the weak properties of cardboard. This issue was mitigated by strapping the pallets. Some pallets still get fractured, but no accidents occur. The other issue was that wooden shards from extensively used pallets hindered the flow of pallets. A potential mitigation strategy is to inspect pallets before use.

5.5.3 Company C

Insight 9: Utilize height
The company is one of the largest global actors in their field with a large, and recently expanded, production facility, storing finished pallets in an area of only 15 x 15 meters. The reason is that the FGW properly utilized the height, with the help of pallet racks. This further accentuates the importance of using storage equipment to fully utilize the available space and increase capacity.

Insight 10: Problems with limited visibility
An ERP system, without a WMS module, where pallets only can be classified as zones but not locations is used. Thus, pallets ready for shipment could be placed either in the tent or terminal and have been assigned the same ERP location regardless. Due to the limited visibility, there have been problems with losing track of pallets, resulting in a tedious effort to retrieve them. This problem highlights the need for visibility of the pallets throughout the whole process, by logging the pallet in a specific location in the information system.

Table 5.3: Insights from company visits

Company	**Insight**
A	Optimize for situation
	Vertical classification
	Stepwise implementation
	Utilize the knowledge of the operators
B	Flexibility of AGVs
	delimitations of AGVs
	Implementation of AGVs
	Material properties negative impact when using flow racks
C	Utilize height
	Problems with limited visibility

5.6 Performance

The KPIs used to evaluate the performance should investigate the whole configuration. That is, both the operations as well as the design and resources.

A suitable set of KPIs for the Alfdex FGW should have a link to all operations. As recapitulation, the different operations performed in the Alfdex FGW are arriving, put-away, pallet-flag picking, SKU picking, marking, and loading. The most time-consuming is the process of pallet-flag picking, which takes approximately 58.5 minutes per day. The second longest, and longest out of the ones that require the use of a forklift, is the SKU-picking with 42 minutes per day. Loading is another crucial operation, sometimes experienced as a bottleneck, which takes around 5.3 minutes per day counting only indoor transportation. These operations specifically, and the others, aggregate to a total operational time of 160 minutes per day, which is the overall metric to reduce for operations. Thus, these four KPIs were deemed appropriate to measure the operations.

The set of KPIs should also include measures of how the design & resources facilitate operations. One such is how large a percentage of pallets are available for picking without inducing any double handling. In practicality for the current configuration, this entails how many pallets are in the outermost position in their respective bins. Another one that is highly relevant for a warehouse is pallet position utilization, whereof main storage utilization is particularly of interest, which includes finished goods SKUs and additional material.

In summary is suggested that Alfdex employ four KPIs to measure the operations; (i) pallet-flag picking, (ii) SKU picking, (iii) loading, and (iv) total operational time. For design and resources, they should use a set of KPIs including (i) pallet face availability and (ii) pallet position utilization. All KPIs are presented in *Figure 5.4* with a description, unit of measurement, and value for the current configuration.

Table 5.4: Key Performance Indicators (KPIs) for Alfdex FGW

Category	KPI	Description	Unit	Value
Operations	Pallet-Flag Picking Time	Average time taken for pallet-flag picking	Minutes/day	58.5
	SKU Picking Time	Average time taken for SKU picking	Minutes/day	42
	Loading Time	Average time taken for loading	Minutes/day	5.3
	Total Operational Time	Total time taken for all operations	Minutes/day	160
Design	Pallet Face Availability	Percentage of pallets available without double handling	Percentage	20%
	Pallet Position Utilization	Percentage of utilized pallet positions in storage	Percentage	80%

6 ARTEFACT DEVELOPMENT

This section aims to portray the design propositions that emerge from an extended exploration of data and analysis, integrating internal factors with insights from external company visits and problem evaluations. These propositions are meant to each entail some tangible and implementable part of the new configuration.

6.1 Design Propositions

The design propositions are based on a combination of previously presented literature, company visit insights, data collection, and analysis that entails several decisions that will be a part of the new warehouse configuration. Each proposition is formulated using the CAMO format. That is each proposition takes the specific **C**ontextual factors at Alfdex into account and presents the relevant **A**ctor involved. The proposition, or **M**echanism, is the change of the warehouse configuration which will increase the performance, or **O**utcome, of the FGW. The outline of the following section is presented in *Figure 6.1*.

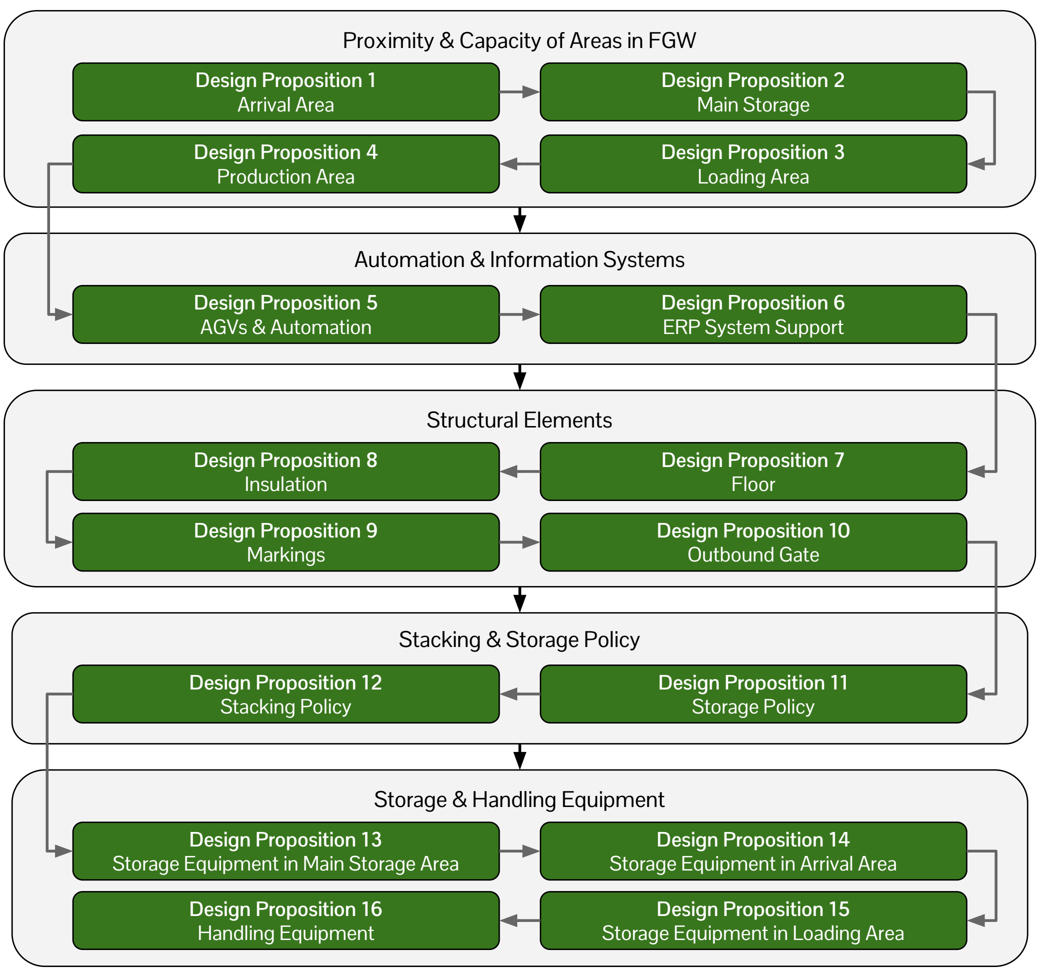

Figure 6.1: Outline of design propositions section.

6.1.1 Proximity & Capacity of Areas in FGW

Design Proposition 1 - Arrival Area
The arrival area should: (i) be near the inbound gate, to receive finished SKUs from production by the production forklift operator, (ii) have at least eight locations with a capacity of at least 20 finished SKUs, (iii) have a capacity of at least 65 additional material SKUs, (iv) to ensure efficient operations while having sufficient capacity.

Currently, SKUs are, and should be, transported individually to the FGW, by the forklift production operators. Since the SKUs to be placed are finished goods they come from the production area. Thus, it is intuitive to place the arrival area close to the inbound gate. Which follows the theory, to *create an as continuous flow as possible* (Bartholdi and Hackman, 2019). The advantages are twofold; (i) the traveling distance is minimized and (ii) separate the forklift flows between production forklift operators and the warehouse workers. The second advantage is in line with the request of the warehouse workers expressed as the problem **Unexpected staff movement**, see *Section 5.4*. Considering the warehouse workers' knowledge is important, according to *Insight 4: Utilize the knowledge of the operators*. With production forklift operators only driving within a designated area near the production gate, the movements in the FGW are minimized.

There should be at least eight bins with a capacity of 20 finished SKUs to ensure that there is always an available arrival bin. The frequency of visually inspecting the arrival bins, by the warehouse workers, is estimated to be once each hour. There are five production lines with an approximate output of 6.7 SKUs per hour. Thus, to ensure that there are available bins if, unlikely but theoretically feasible, more than two production lines change the article produced within an hour, there should be at least eight arrival bins. This is also a safety measure as the frequency of visual inspections can vary, up to two hours, if there are larger incoming shipments in the RMW that need to be handled. The number of SKUs, at least 20, is derived similarly. With the current average production output, this corresponds to three hours of normal production.

Lastly, the arrival area should have at least 65 stock locations for Additional Material. This corresponds to the aggregate of the SKUs currently stored in the *WIP* and *Additional Material - Production* areas, as illustrated in *Figure 4.10*. By storing these SKUs in the arrival area they are easy to retrieve by the production forklift operators. This is also in line with the vision to separate the forklift flows in the FGW.

Design Proposition 2 - Main Storage Proximity & Capacity
The main storage area of the FGW should: (i) have a capacity of at least 600 finished goods SKUs, whereof 400 EU pallets and 200 lattice boxes, (ii) have a capacity of at least 135 additional material SKUs, whereof minimum 40 locations with extra height, (iii) have a U-flow configuration, (iv) to enable efficient put-away and picking by the warehouse workers.

The capacity of the main storage of the FGW is essential for efficient put-away and picking operations. Currently, the maximum capacity for finished SKUs is 558, as described in

Paragraph 4.3.1.2. The distribution between the types of SKUs is based on the distribution of the sales for 2023, as seen in *Figure 4.6*, where a third of the sales were lattice boxes and the rest EU-pallets. Of the finished SKUs stored in the FGW 33.7% are lattice boxes while 66.3% are EU-pallets, as illustrated in *Figure 4.6*. This is lower than the peak volume of 617 SKUs, where 670 SKUs in the FGW and 53 SKUs in the loading area as seen in *Figure 4.1*. During peaks in volume, the FGW gets crowded which inhibits forklift movement, whose effect is accentuated by the ten deep storage bins. Having an increased capacity of at least 600 finished goods SKUs corresponds to 97% of the peak volume, where 400 locations are dedicated to EU-pallet and 200 to lattice boxes. By dimensioning the FGW to the historical., and predicted future, peak demands sufficient capacity is assured which will not negatively impact operations.

The two operations mainly affected, the put-away and picking operations, will be improved by keeping the U-flow configuration and increasing the capacity. The U-flow configuration, that is currently used in practice, is suitable for use in the new configuration as well. The contextual factors of Alfdex where the demand is strongly skewed, as can be seen in *Figures 5.4 and 5.5*, make the U-flow suitable according to Bartholdi and Hackman (2019) and Huertas et al. (2007). A U-flow configuration and increasing the overall capacity will decrease the negative impact of **Disruptive warehouse clutter**, which is listed as one of the main problems, on operations. These are important to improve as in theory picking often is the most important operation and constitutes most of a warehouse's operating expenses according to Bartholdi and Hackman (2019), and practice overlap. From the current state VSM, see *Figure 5.6*, the forklift operations, where the picking operation is the most time expensive, constitute most of the operations time in the FGW. Furthermore, Bartholdi and Hackman (2019) accentuate that *create an as continuous flow as possible*, by eliminating double handling, is an important principle in designing an FGW.

The number of pallet locations dedicated to the packaging material is estimated to be 135 pallets. This number is based on measurements during a day with relatively many additional material SKUs in stock, to again dimension after maximum need. Additionally, at least 40 stock locations should have additional height available to enable the additional material SKUs that are wider and higher than traditional SKUs. These SKUs correspond to the ones located in the emergent storage area and two pallet racks, as seen in *Figure 4.10*. The SKUs currently located in the emergent storage area are crucial to manage as it is a large contributor to the **Disruptive warehouse clutter** and **Challenging to drive forklift** problems, which are ranked high in both the Muda Matrices, see *Section 5.4*. Thus, by increasing the capacity in the main storage for additional material SKUs, the warehouse workers are not limited by the emergent storage area which ensures effective truck operations.

Design Proposition 3 - Loading Area Proximity & Capacity
The loading area should: (i) be located close to outgoing, (ii) have a capacity of at least five locations with a capacity of at least 200 SKUs, (iii) enable quick loading operations by the warehouse workers.

The loading of finished SKUs onto trucks can at times be a bottleneck operation. The time it takes to operate depends on where the loading area is located. Closer to the outgoing gate means shorter travel time. This is crucial as the order and shipping process is important to maintain a high service level to customers (de Koster et al., 2007). During interviews, it was expressed that due to coordination delimitations, there are no time slots as shipments are planned per day, and several trucks can arrive at the same time, which is stressful for warehouse workers. This includes both incoming and outgoing material flows, as the warehouse workers are responsible for both unloading and loading. The travel time from the loading area to the outbound gate, which is measured and presented in *Figure 5.6*, constitutes a part of the total loading time. Thus, to not increase the load on warehouse workers during peaks in activity, the travel time for loading should not increase for the new configuration. Consequently, the loading area must be located near the outbound gate.

The loading area capacity of at least 200 SKUs shall be divided over five or more locations. The ideal number of stock locations depends on the number of trucks to be loaded each day, which is directly linked to the number of customers to be shipped to which each day is usually around 3 - 4 customers, whereof 2 - 3 larger. The number rarely exceeds five, as mentioned in interviews and illustrated in *Figure 5.1.* The largest number of SKUs shipped during one day, during the sample period, was 205 SKUs, see *Figure 4.2.* The average is considerably lower, with 86 SKUs. However, it is appropriate to dimension after the maximum demand as the SKUs in the loading area heavily influence the operations and accessibility of other SKUs in the FGW, as illustrated in the heatmaps in *Figure 5.9 and 5.10.* Additionally, the FGW currently has problems with **Stack-changing upon loading and Truck arrives one day late**. By having proper capacity in the loading area there is room for restacking, and storing SKUs an extra day, on most days. Thus, with a loading area with at least five stock locations with a combined capacity of at least 200 SKUs, corresponding to 97.5% of the peak capacity, the loading area is better suited to ensure fast and efficient operations in the FGW.

Design Proposition 4 - Production Area Proximity & Capacity
The requested available area for production should: (i) be cohesive, (ii) as large as possible, given that other factors such as capacity and operations improvements are sufficient, (iii) be located to enable production workers to reach it and work there safely.

Alfdex has requested that a part of the FGW, given that the reconfiguration has enough capacity and improved operations, should be dedicated to a production area. Currently, as stated in the problem formulation in *Section 1.3*, Alfdex has had rapid growth in the last years where expansions have made the production area cramped. Thus, by placing smaller operations in the FGW, space could be freed up in the production area to enable future expansions or diversification. There is always a trade-off between space and capacity in a warehouse. Given sufficient capacity and space for smooth operations, space can be used for other purposes than storing. This is in line with *Insight 1: Optimize for situation* and the contingency approach, as stated by (Kembro and Norrman, 2021), that the solution should match the contextual situation of the company. To make it available for production workers it must be located to be able to reach it safely from the inbound gate, see *Figure 4.10*, to avoid increasing the stated problem of **Unexpected staff movement**, from *Section 5.4*.

6.1.2 Automation & Information System

Design Proposition 5 - AGVs & Automation
The Alfdex FGW should not employ AGVs or any other automation solution currently, as the potential time savings are limited, and the current warehouse workers are better at handling the SKUs as stacks.

The case for automation is largely a question of costs, where a case where the savings make up for it cannot be found. The visit at *Company B* reinforces literature, see Rowley (2000), which identifies that reduced operating costs are one of the key motivators for implementing AGVs. The logistics manager of *Company C* held a similar stance for not exploring AGVs further, given their operational context. At Alfdex, the daily time-savings through AGVs could be categorized into put-away and picking, given that AGVs are not suited for shipping tasks. This is due to the complexities of AGV transportation outside the warehouse, which involves sensor integration and system support, truck loading, and certain orders necessitating restacking of SKUs. The total potential time savings for put-away, nine minutes as seen in *Figure 5.6*, and picking 42 minutes, does not exceed an hour per day. From a cost-benefit perspective the combined time savings, and by extension the saved labor cost, do not nearly compensate for the increased costs of upgrading to AGVs.

Another issue is the interface between the AGVs, human workers, and storage equipment. At *Company B* the intersection with workers, expressed in *Insight 5: Flexibility of AGVs*, there was no problem with the human interface after the AGVs had been implemented. However, there was a considerable adjustment period before the employees were comfortable working in connection to the AGVs, as expressed in *Insight 7: Implementation of AGVs*. In addition, it becomes more difficult to use temporary workers who are not used to working in connection with AGVs. A main benefit of incorporating AGVs is that the overall reliability, in this case of put-away and picking, is increased according to Rowley (2000). Poor precision, resulting in incorrect picks, was however not identified as a prominent problem at Alfdex. The AGVs are limited in the interface with handling equipment, as seen in *Insight 6: delimitations of AGVs* and *Insight 8: Material properties negative impact when using flow racks*. Alfdex currently employs wooden and cardboard EU-pallets which negatively impacts the functioning of AGVs.

Implementing AGVs increases the risk of malfunctions. The warehouse manager at *Company B* also spoke of the risks of malfunction which occurred, sometimes without any apparent cause, at the company, see *Insight 6: delimitations of AGVs*. The logistics manager at *Company A* recognizes that specialized trucks implicate more risk when in need of repair or a replacement. Due to the limited operating time in the FGW, it would not be justifiable to have more than one AGV. A sole AGV failure, responsible for put-away and picking, would halt all operations in the FGW. Arriving pallets would congest around the inbound gate and no pallet-picking would hamper shipping. Although one individual could manage these processes for the duration of the malfunction it would require a backup of handling- and technical equipment to interact with the system the same way that the AGVs do. The use of AGVs would also require extensive investments in developing the WMS or ERP further. According to *Insight 3: Stepwise implementation*, it is wise to expand one step at a time, and not take on a large AGV implementation project in addition to the new warehouse configuration. Similarly, Kembro & Norrman (2022) emphasize that the journey towards a *smart warehouse* is likely to be stepwise, either in the direction of automation or connectivity, and Alfdex should rather enhance connectivity.

Design Proposition 6 - ERP System Support

The ERP system support should be increased: (i) by dedicating each SKU to a single stock location, (ii) by using handheld scanners and forklift computers, (iii) that guides the put-away and SKU picking operations, (iv) to improve operations, by eliminating the pallet flag picking process performed by the shipping personnel and decrease the time searching for SKUs.

Increasing the granularity and accuracy of the ERP system will lead to increased control of the inventory. All visited companies had a WMS capable of managing the full inventory of articles and pallet positions. Alfdex, handling a significant volume of pallets, ranks third among these companies. The benefits of a WMS—especially in rapidly locating pallets for picking—were highlighted during *Company Visit 3*. Alfdex, with its substantial flow of pallets, stands to benefit notably from a WMS, particularly since picking, the most time-intensive operation in their setup, is where a WMS excels. The main improvement will come from dividing the FGW by stock locations, instead of treating it as a black box. To accomplish this, the FGW has to be divided into zones, and have single stock locations where every SKU-movement is logged. This is per the principle to *scan the product at all key decision points*, according to Bartholdi and Hackman (2019). Increasing the control will fight the current problems of **Difficulties finding pallets and Incorrect stock levels**, which were mentioned as a problem at *Company C* as *Insight 10: Problems with limited visibility*. Furthermore, it is easier to audit inventory, especially when SKUs are misplaced, if stock levels at each location are accurately described in the system. These improvements will be achieved by dedicating each SKU to a specific location and using handheld scanners, which will rapidly enhance granularity and reduce the likelihood of misplacing SKUs.

Improving the ERP system, and implementing a WMS, will improve several operations. Increasing the accuracy of the ERP system will eliminate the pallet flag-picking operation. The process currently has three main features; (i) follow FIFO, (ii) make sure the number of SKUs from the ERP system is in the FGW and (iii) indicate which SKUs to be picked in the SKU picking. All these functions can and should, be performed by the ERP system. The potential time savings are large, as the shipping coordinators spend on average approximately one hour on pallet flag picking each day, as seen in *Figure 5.6*. Additionally, the extra pallet flag that is ripped off does not have to be nailed onto the pallet, which saves time in the production. With an increased system support the warehouse workers can be guided in the put-away and picking processes. This is achieved by system support, using forklift computers, suggesting stock locations in put-away and generating a pick for SKU picking, sorting after the oldest pallets. The transition into this system will be smooth, as the same system is currently used in the RMW. Thus, Alfdex knows that it is possible and how to operate these functionalities within the current ERP system. Additionally, the warehouse workers and production forklift operators are aware of the working methods, as these are currently employed in the RMW.

6.1.3 Structural Elements

Design Proposition 7 - Concrete floor

A concrete floor should be installed: (i) to replace the current asphalt floor, (ii) to enable pallet racks in the FGW, (iii) to improve safety and decrease the strain on handling equipment during operations, (iv) and improve the working environment of the warehouse workers by improving air quality.

A concrete floor would allow for pallet racks to be constructed and simultaneously combat employee problems with the present floor. Having a concrete floor is standard for a warehouse, as seen in all the company visits and the literature (Bartholdi & Hackman, 2019). Currently, the floor is asphalt which means that pallet racks must be secured to a wall, severely limiting how they are placed and used in the FGW. The interviews with FGW employees highlighted the problems of **Uneven surface in FGW, unfavorable working conditions, and Challenging to drive forklift**. These problems are both connected to sub-optimal operational performance as well as working environment and safety. With the uneven surface, with wells in the drive paths, the forklift cannot operate at full speed. Additionally, the asphalt floor gets extremely dirty which leads to a lot of particles in the air, which has been seen to be a health hazard (Strelyaeva et al., 2019). Thus, the warehouse workers are currently using a counterbalance truck with a cabin to combat this. Furthermore, it is believed that the frequent breakdown is largely attributed to the current production forklifts unsuitable for the surface, which is supported by literature (Garber, 2005). For the FGW to become a satisfactory working environment for the production forklift operators, shipping coordinators, and potentially production operators, the air quality and cleanliness must be improved. This is achieved by switching to a concrete floor, which will enable pallet racks as well as a better working environment and performance.

Design Proposition 8 - Insulation

The FGW building should, which is currently not the case, be insulated to make for better working conditions for the warehouse workers, production forklift operators, and potential production workers.

Insulating the FGW will lead to improvements in the working environment. Currently, this is not the case, leading to the problem of **Unfavorable working conditions** which encompasses the uncomfortable temperatures in the FGW. That is, cold in the winter and hot in the summer. In the weekly meeting with the company supervisor, the feasibility of reconditioning the FGW and insulating its walls was discussed. Insulation and flooring had already been added to the adjacent RMW in the facility, which was originally constructed similarly to the FGW, supporting the feasibility of this improvement. It was concluded that the FGW should undergo the same rejuvenation to take advantage of the increased productivity and the improved working conditions it would entail according to Adhvaryu et al. (2018). The threat to worker health by exposure to cold over time, according to Akbar-Khanzadeh et al. (2009), is even more relevant to consider with the future FGW as it would also contain a production area, as stated in *Design Proposition 4*, which would employ someone for consecutive hours. Insulating the FGW would improve the working conditions and remove the currently used epithet "cold storage".

Design Proposition 9 - Markings
All sections of the FGW should be clearly outlined: (i) through clearly demarcating the storage bins, in the arrival- and loading area, and the production area, (ii) to assist production forklift operators and warehouse workers in placing SKUs, (iii) to guide and limit the potential production operators, to and within the production area, (iv) to increase the safety and working environment, (v) and decrease the warehouse clutter.

Clearly outlining and marking the different sections of the FGW will lead to multiple improvements. Several of the problems that received a high ranking in both Muda Matrices can be attributed to the problem of stray material, both in terms of pallets and other material, being placed in the FGW. Out of the three most critical problems, in the waste matrix, both **Disruptive warehouse clutter** and **Challenging to drive forklift** have a clear connection to this. The current uncertainty in terms of where to place stray pallets is best addressed by clearly outlining different warehouse sections with markers and ensuring all required areas are present and accessible. Additionally, as concluded by de Koster et al. (2011), this will decrease the risk of injury by making accidents less probable. Thus, with clear markings in the FGW, the operators will be guided, which will decrease the clutter which in turn improves the working environment and safety.

Design Proposition 10 - Move the outbound gate
The outbound gate should: (i) be moved, out from the wall connecting to the RMW to the middle of the FGW, (ii) to allow for favorable placement of the loading area, (iii) to shorten the loading travel time for the warehouse workers.

The current placement of the outbound gate in close connection to the wall to the RMW, as seen in *Figure 4.10*, is unfavorable. As is currently the case, only single deep bins are available on the left-hand side, while the main loading area on the right-hand side interferes with the customer bins. The latter is stated as the problems of **Restricted SKU availability** and **Challenging to drive forklift**, during the interviews. To be able to have the storage of finished goods SKUs on the right-hand side, and a sufficiently large loading area on the left-hand side, the outbound gate must be moved to the middle of the warehouse. This is in line with the principle to *create an as continuous flow as possible*, as stated by Bartholdi and Hackman (2019). Where a suitably located loading area will enable an efficient loading process. The investment in installing a new gate is relatively small, compared to the deemed improvement. Consequently, the outbound gate should be moved to improve the layout of the loading area and the loading process.

6.1.4 Stacking & Storage Policy

Design Proposition 11 - Stacking Policy
The new configuration should employ a stacking policy: (i) that handles the finished goods SKUs separately, either individually or as stacks, (ii) based on their sales characteristics, where finished goods SKUs with an average number of SKUs per shipment above 4 should be handled as stacks (iii) to reduce time required throughout operations, both upon arrival by production workers to handling by warehouse workers.

All Alfdex SKUs are stackable, which enables SKUs to be handled in stacks of three, regardless of the type of article, to the same customer. While it is almost a necessity to increase the already low pallet availability in main storage, there is also an argument for this in terms of reducing the operational times as stacks can be handled as easily as stray pallets. This is illustrated in *Figure 5.6*, where the time per SKU is low for all forklift operations when dealing with stacks. This is suitable since the picking process generally makes up most of the warehouse's operation expenses (Bartholdi and Hackman, 2019). Handling stacks instead of single SKUs reduces operational times, on average to a third.

It is suitable to handle articles as stacks or individually based on sales characteristics. In *Figure 4.8* and *Figure 5.5* distinct differences in sold quantity between articles became evident. Combining these with the insights given by *Figure 5.3*, on describing the average number of SKUs ordered per shipment for each article, supports the idea that the reconfigured should employ a stacking policy of three pallets for the high-volume-ordered articles. This policy will be applied to the 24 articles above the stacking limit, of four SKUs per order, corresponding to 89.5% of the volume. However, it is not a suitable strategy for low-volume-ordered articles. During observations, it became evident that for low-volume-ordered articles the warehouse worker frequently had to pick apart a stack to extract individual SKUs. Hence, for the articles ordered in smaller quantities, individual SKU handling is more appropriate.

Design Proposition 12 - Storage Policy
The FGW should adopt a zone-based storage policy for floor positions in the main storage area, with one zone dedicated to lattice boxes, another to EU-pallets and a third with mixed SKUs zone, and a shared storage for pallet racks.

A zone-based storage policy for the floor positions is appropriate for Alfdex. The main reason is the large difference in dimensions and customers for the different types of SKUs. Since the lattice boxes, compared to EU pallets, are considerably smaller, more SKUs can be fitted into the same space. Additionally, as the SKUs are for different customers, the flows can be separated. The current configuration utilizes a modified zone-based policy where the different bins are dedicated to a specific customer. The share of SKU types over time is approximately a third of lattice boxes and the remaining EU-pallets, see *Figure 4.6*. However, the composition varies rapidly between days, as seen in *Figures 5.9 and 5.10*. Thus, a mixed SKUs zone is suitable to adjust for fluctuations. The articles to be stored in the floor stock locations are the ones above the stacking limit, as suggested in **Design Proposition 11**. Using the zone-based policy, with shared storage locations within, is appropriate as flexibility and utilization increase (Bartholdi and Hackman, 2019).

A shared storage policy for the SKUs placed in the storage racks is preferable. Here, the element of utilization and flexibility is crucial, as capacity is a requirement for the new solution. For the SKUs that are placed in the upper sections of the pallet racks, being below the stacking limit, there are no specific dedicated zones, and the SKUs are placed randomly. There is one exception, the four-collar high EU pallets, which are to be placed on the top level of the storage racks, where there is more space. The types of SKUs will vary, including finished goods SKUs and additional materials. Consequently, each location can be used for each SKU, which is a main advantage of the shared storage policy (Gu et al., 2007).

6.1.5 Storage & Handing Equipment

Design Proposition 13 - Storage Equipment in Arrival Area
The arrival area should employ pallet racks: (i) that are single deep, (ii) that are six levels high, (iii) where levels 1 -3 are "open", enabling stacked SKUs in floor positions, for finished goods SKUs. (iv) where levels 4 - 6 are individual stock locations, for SKUs to be repackaged and additional material, (v) to streamline the put-away operation, for the warehouse workers, and the picking back to production, for the production forklift operators.

The pallet racks, combining open and conventional storage locations, are suitable for the arrival area. The solution is derived from *Insight 2: Vertical Classification*, where the top and bottom locations have different purposes in the pallet rack. The SKU output from production is varied, in terms of articles, and to avoid unnecessary double handling upon put-away each unique article should have its own floor position. Here the finished goods SKUs will be stacked, one article per stock location, which increases the capacity (Bartholdi and Hackman, 2019). Although the utilization of the arrival area is generally low, due to regular put-away, it can at times peak due to warehouse workers being tied up by receiving or departing trucks. This necessitates that the arrival area has several shared floor positions so that there is always an available stock location. This way articles will not be mixed. The arrival bins should be single deep to ensure visibility so that the warehouse workers know when there are SKUs ready for put-away. To fully maximize the potential of also using the pallet positions above, single deep racks are suitable. Here additional material and repackaging SKUs, that will go back into production, are stored. The unique combination of combining floor storage underneath conventional pallet rack stock locations is in line with the contingency approach, where the solution is tailored to contextual factors (Kembro and Norrman, 2021).

Design Proposition 14 - Storage Equipment in Main Storage Area
The main storage area should employ pallet racks: (i) that are single deep, (ii) are separated into two types of pallet racks, both handling finished goods SKUs, ***and M1: ordinary palletized additional material and M2: special, extra-large, additional material.***

M1: *(iii) that are six levels high, (iv) where levels 1 -3 are "open", enabling stacked SKUs in floor positions, for finished goods SKUs. (v) where levels 4 - 5 are individual stock locations, for SKUs to be repackaged and additional material, (vi) where level 6 are individual stock locations, for slow movers and four collar pallets.*

M2: *(iii) that are three levels high but double the height (iv) where levels 1 -3 are "open", enabling stacked SKUs in floor positions, for finished goods SKUs. (v) where levels 4 - 5 are "open", to enable extra-large and wide additional material SKUs, (vi) where level 6 are individual stock locations, and (vii) to streamline the put-away and picking operations for the warehouse workers. (vii) to streamline the put-away a picking operations for the warehouse workers, by eliminating the double handling.*

The main storage should employ single-deep pallet racks, allowing for stacking in bottom locations and individual storage in top locations. Currently, a critical issue is the limited availability of pallets in the main storage area, resulting in poor operational performance. As seen in *Figure 5.8*, 46% of picking operations are categorized as waste, hence avoidable with an optimized rack configuration. The storage equipment should support, and simplify, following FIFO which is a requirement. Furthermore, as concluded in *Subsection 4.1.4*, the future product assortment is estimated to be even greater. Single-deep racks, despite occupying more space, provide the best solution. These ensure that all the SKUs are always accessible, enabling FIFO and eliminating the risk of honeycombing (Bartholdi and Hackman, 2019).

The two storage equipment variants, **M1 and M2**, will be used in the new configuration. The solution is based on *Insight 1: Optimize for Situation* and will be able to handle all the types of SKUs in the FGW. The pallet racks are based on vertical classification, inspired by *Insight 2: Vertical Classification*, where both individual stacks of SKUs can be stored on different levels. Both pallet rack variants can handle ordinary pallets of finished goods SKUs. However, they also need to handle additional material, which comes in different sizes and shapes. Most are standard EU pallets, often three collars, which will be stored in **M1**. However, some of the additional material SKUs are double the height or width of standard pallets which require "open" stock locations, that is not individual locations horizontally separated by beams. The special additional material SKUs will be stored in **M2**. This storage equipment for the main storage area is according to the contingency approach, which takes contextual factors such as SKU characteristics solution into account (Kembro and Norrman, 2021).

Design Proposition 15 - Storage Equipment in Loading Area
The loading area should: (i) use floor storage locations, hence no storage equipment, (ii) with clearly demarcated outline of storage area and bins, (iii) enable all SKUs can be marked by the shipping coordinators while warehouse workers can easily navigate and gain awareness of SKUs and orders.

The use of floor storage is the best solution for the loading area. The SKUs are loaded onto the truck in stacks, either as three or four, which is one current issue stated as the problem **Stack-changing upon loading**. Today, the re-stacking is minor, from three to four high. However, this process would be increasingly more time-consuming if the SKUs were stored individually, adding even more work to the stressful loading process, which makes conventional storage equipment unfavorable. Additionally, the marking operation must take place in this stage of the process, which requires the SKUs to be stored at a convenient height to enable marking by the shipping coordinators. Furthermore, floor storage offers the advantage of easy visibility and oversight, as there is no overhead storage to obstruct, allowing for a more comprehensive overview of stored items. Warehouse workers particularly benefit from the organized and structured layout, which significantly boosts their efficiency in quickly locating and accurately identifying specific pallets and orders amidst the operations. Taking all these contextual factors into account, following the contingency approach (Kembro and Norrman, 2021), using floor storage is the best solution for Alfdex.

Design Proposition 16 - Handling Equipment
The new configuration should include handling equipment: (i) with a strategy that is like the current one, (ii) by keeping the counter-balance truck and adding one or two reach-trucks, (iii) that can be connected to the ERP system, (iv) which will guide and simplify the operations performed by the warehouse workers.

Alfdex should use standardized handling equipment to decrease costs and ensure availability. Company A purposefully chose standardized configurations for their different forklifts, as stated in *Insight 1: Optimize for Situation*. Standard forklifts are by nature cheaper than special versions. Additionally, they are easier to repair or replace. This is relevant for Alfdex where forklifts frequently break down. Although the breakdowns are related to the problem of **Uneven surface in FGW**, which has been addressed, unevenness between sections still exists. Breakdowns will also occur occasionally regardless of a warehouse's physicality.

The handling equipment to be used in the FGW is the currently used counterbalance truck and one or two reach trucks. Correct handling equipment is crucial as it gives efficient put-away and picking processes, enabling convenient storage locations (Bartholdi and Hackman, 2019). The forklifts need to access all six levels of the storage equipment, as described in **Design Propositions 13 and 14**. This is most suitable with a reach truck, which is easy to use and requires less aisle width than the counterbalance truck. Alfdex should initially invest in one reach truck and, if insufficient, add another. The reach truck(s) should be connected to the ERP system, using a forklift computer, to guide the warehouse workers in the put-away and picking operation. The counterbalance truck is still needed, as it is needed for loading SKUs on trucks.

6.2 Implications for Configuration Elements

The design propositions have implications for several warehouse configuration elements. These are illustrated in *Figure 6.2*. The implications for operations are illustrated with blue lines, while implications for design & resources are black. If a proposition has implications for all the operations its arrow ends at the larger rectangle incorporating all operations, see blue arrow from design proposition 11, while if it impacts a single operation its arrow ends the specific impacted configuration element, see blue arrow from design proposition 12. Due to the structure of the design propositions, following the CAMO format, each one has implications for both operations as well as design and resources. The figure is complex but illustrates that the design propositions have implications for several elements simultaneously in the new configuration. Each design proposition category's impact is discussed below.

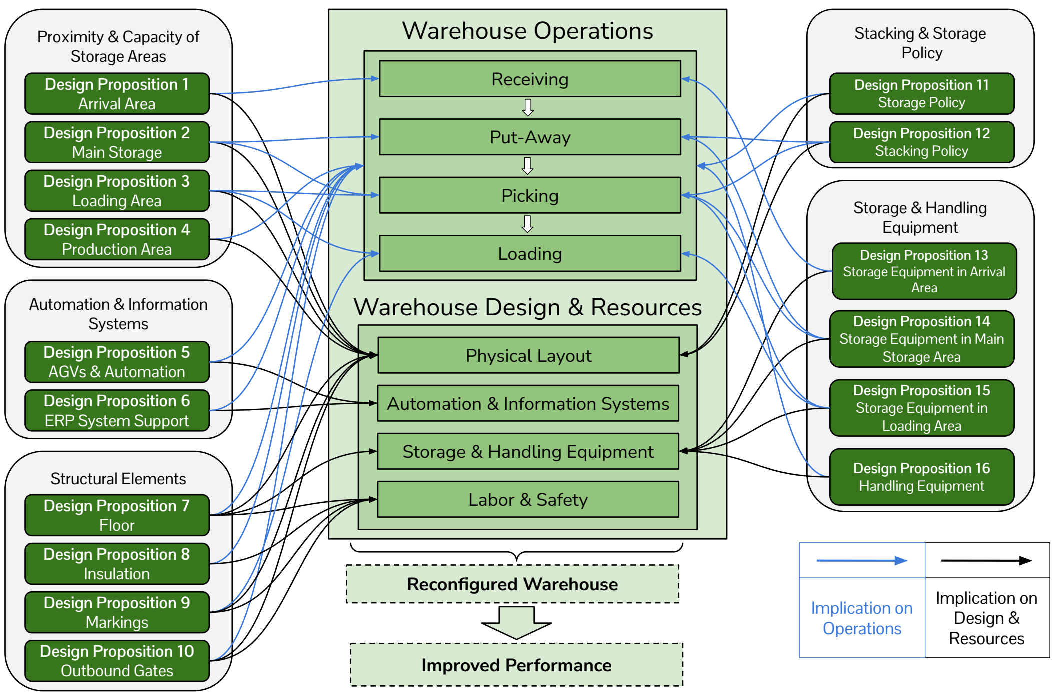

Figure 6.2: Implications of Design Propositions on Configuration Elements.

6.2.1 Proximity & Capacity of Storage Areas

The proximity and capacity of storage areas impact both operations and design & resources. The effect on operations is distinctive to each proposition, as each proposition is linked to a specific area of the FGW. Hence, design proposition 1, which targets the arrival area, affects the receiving process. This is due to receiving consisting of production forklift operators transporting SKUs from the production area to the arrival bins. By ensuring the appropriate proximity and capacity of the arrival bins, the receiving operation will transpire smoothly. The same holds for the other operations, with each design proposition targeting an area. In terms of design & resources, the design propositions affect the physical layout. The proximity constraints of design propositions 1 and 3, affect the physical layout of the FGW.

6.2.2 Automation & Information Systems

The automation & information system propositions target AGVs & automation as well as the overall ERP system support. The AGV & Automation proposition is binary, which states that it should not be used. Hence, it has implications for all operations, which would otherwise be automated to some extent. The same is true for the ERP system support. The increase in system support, through worker guidance, is expected to affect all operations. Automation & information system design propositions impact the design and resources, by affecting what level of the automation & information systems are used.

6.2.3 Structural Elements

The structural elements improve all operations as well as labor & safety, the last in the form of safety and working conditions for the warehouse workers. The design propositions are multifaceted but all attempt to improve both the building and internal elements. By implementing an even floor, and removing the wells, operations naturally improve. Additionally, safety increases as there is less risk of dropping SKUs, which is crucial when handling several SKUs at a time. This enables the use of reach trucks in the FGW, instead of the more cumbersome counterbalance truck. By insulating the FGW the working conditions of the warehouse workers will improve, and hopefully, the "cold warehouse" stamp will be erased.

The same reasoning holds for markings and the outbound gate. Clear markings eliminate SKUs in unwanted positions and help avoid another emergent storage area, as in *Figure 4.10*. This means fewer obstacles to operations. In the same manner, it improves the working conditions by removing the irritation of having to deal with unwanted SKUs randomly placed in the FGW. Furthermore, the markings and outbound gate are essential for clearly outlining and isolating forklift traffic, and respectively increasing the capacity of the loading area. Thus, these propositions also impact the physical layout of the FGW.

6.2.4 Stacking & Storage Policy

The stacking & storage policy design propositions will impact all the operations and the physical layout of the FGW. The stacking policy, whether SKUs should be handled as stacks or individually depending on typical order volume, impacts all the operations. The storage policy, where SKUs should be placed in the main storage area, only affects the put-away and picking operations. However, both design propositions will impact the physical layout, as the layout must enable the SKUs to be handled as stack or individually as well as differentiating between the attractiveness of the storage locations.

6.2.5 Storage & Handling Equipment

The design propositions for the storage & handling equipment have implications for all operations, storage- and handling equipment. The use of storage equipment in each area impacts operations to and from that area. Thus, each area's proposition will impact the corresponding operation. The handling equipment will, however, impact all operations, as it is used throughout. All the storage & handling equipment design propositions will naturally impact the storage & handling equipment used in the reconfigured FGW.

6.3 New Configuration

This section presents the new configuration. As a conceptual figure that captures layout, storage equipment, and storage policy, see *Figure 6.3*. The new configuration has many similarities with the current one. Neither the inbound- and yard gate nor the doors have been moved. The current pallet racks are reused, although to a limit, see *Paragraph 6.3.2.2*. The areas are situated relatively close to their original location. The following subsection will break down the different concrete configuration elements in the following order: *Warehouse Operations*, with the various operations. *Warehouse Design & Resources* in the form of *physical layout*, *storage equipment*, *handling equipment*, *automation & information systems* and *labor & safety*. Lastly, the *performance* is presented.

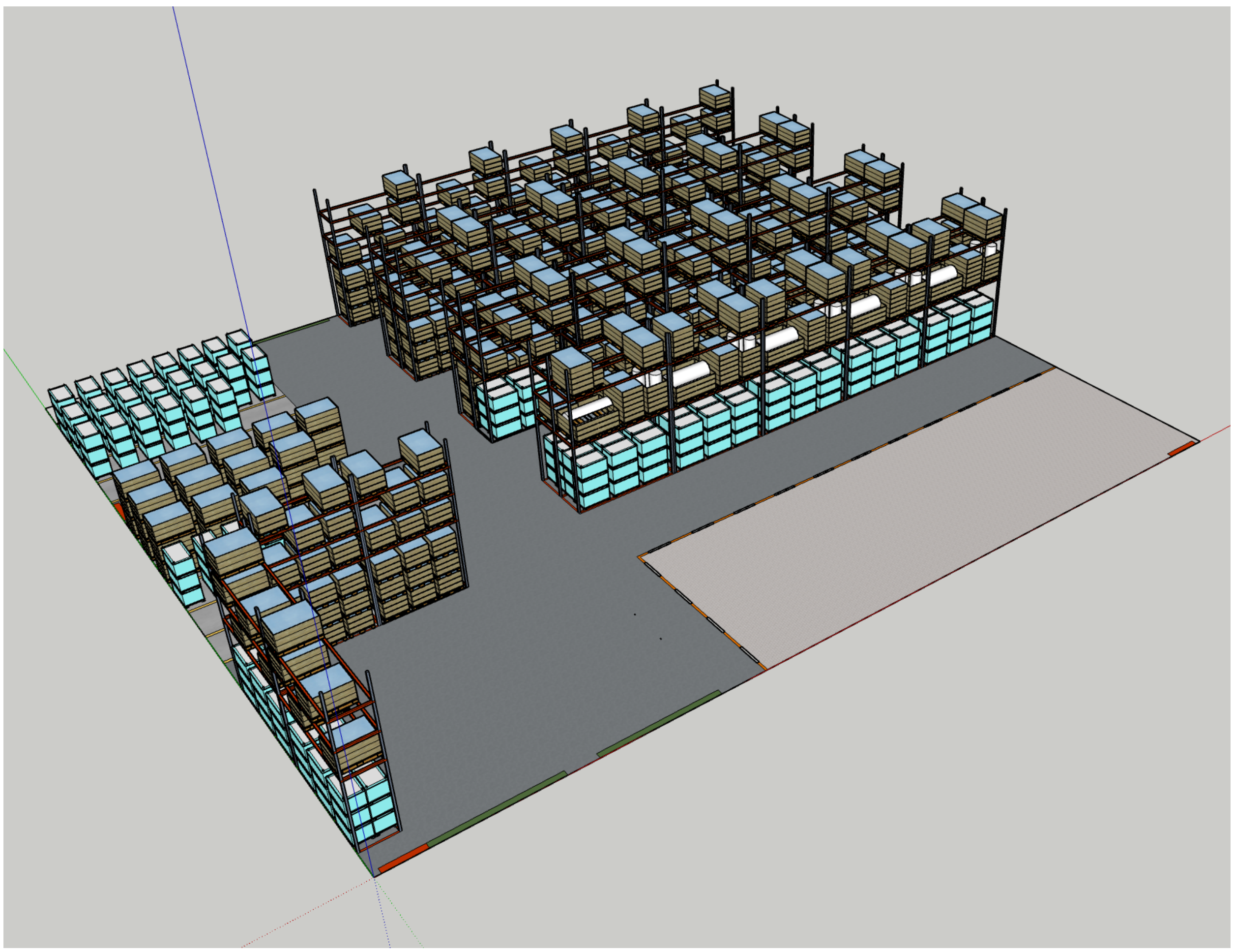

Figure 6.3: Conceptual design of the new warehouse.

6.3.1 Warehouse Operations

The new configuration will streamline operations. The updated VSM, describing the future state, is illustrated in *Figure 6.4*. The main improvement is the removal of the pallet flag picking, which currently corresponds to 58.5 minutes per day, which frees up time for the shipping coordinators. In addition to the obvious time saving, it is also a large improvement in the working conditions of the shipping coordinators, as the pallet flag-picking process is strenuous. Another improvement is the one in SKU picking, where the double handling currently accounts for 46%, *see Figure 5.8*, is eliminated. However, the remaining operations are expected to be minimally, or not at all, affected by the new configuration.

The new configuration means an increased use of the ERP system. The warehouse workers, and shipping coordinators, will be guided with system support when conducting operations, instead of relying on pallet flags. Additionally, email communication will be limited in favor of using the ERP system. To conclude, the reconfigured FGW will make operations more efficient, resulting in a decrease in the total time spent on operations each day.

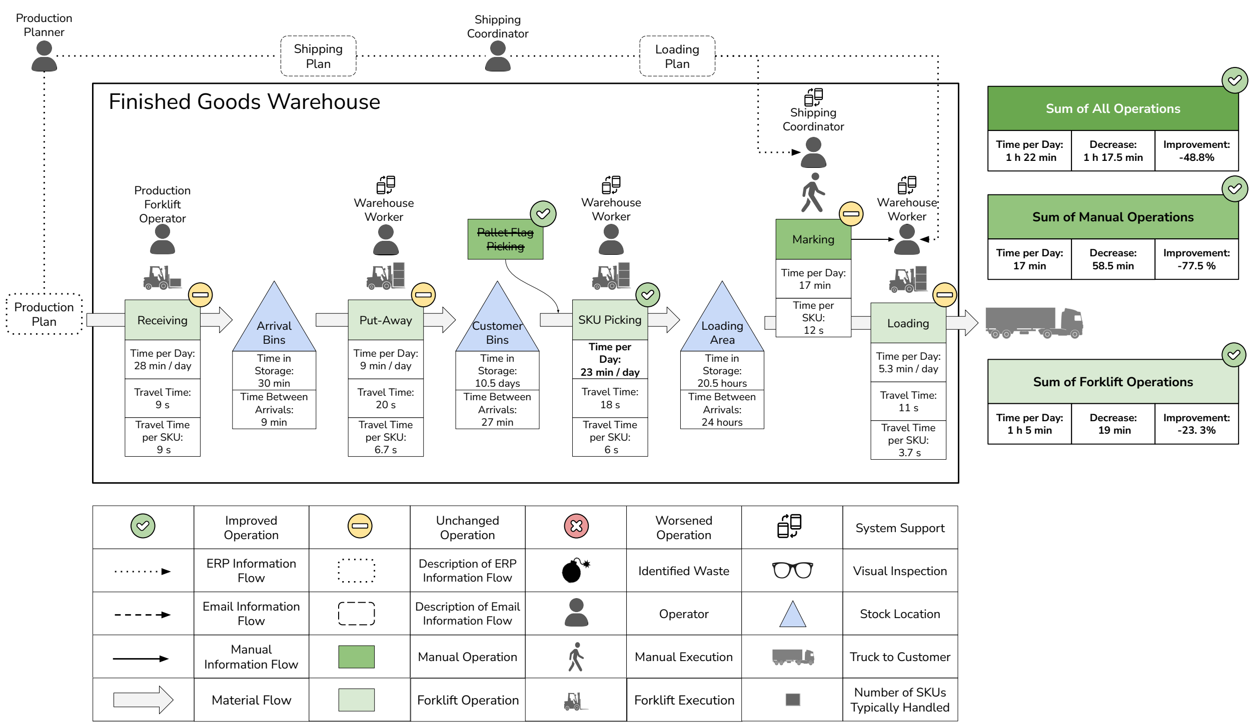

Figure 6.4: Future State VSM, for the new configuration.

6.3.2 Warehouse Design & Resources

This part revisits the features of *Warehouse Design & Resources* and in doing so lays the foundation for all physical attributes of the new configuration.

6.3.2.1 Physical Layout

The layout of the FGW is altered to fit in with all changes that the design propositions entail. The new layout is shown in *Figure 6.5*. The top left floor bins constitute the loading area, the bottom left pallet racks are the arrival area, and the rows of pallet racks on the right-hand side make up the main storage. The main storage area's bottom stock locations are divided into zones, storing lattice boxes and EU pallets separately, with a zone for mixed SKUs to cope with fluctuations in the stock composition. Notably, it also contains an area designated for production, referred to as *Production area*, of 125 square meters, or 6.6 m times 18.8 m (top) and 19.07 m (bottom). The new layout uses three different types of single deep racks; M1, M2, and A which are further discussed in *Paragraph 6.3.2.2*. The capacity, aisle width, and outbound gate are discussed further in the text below.

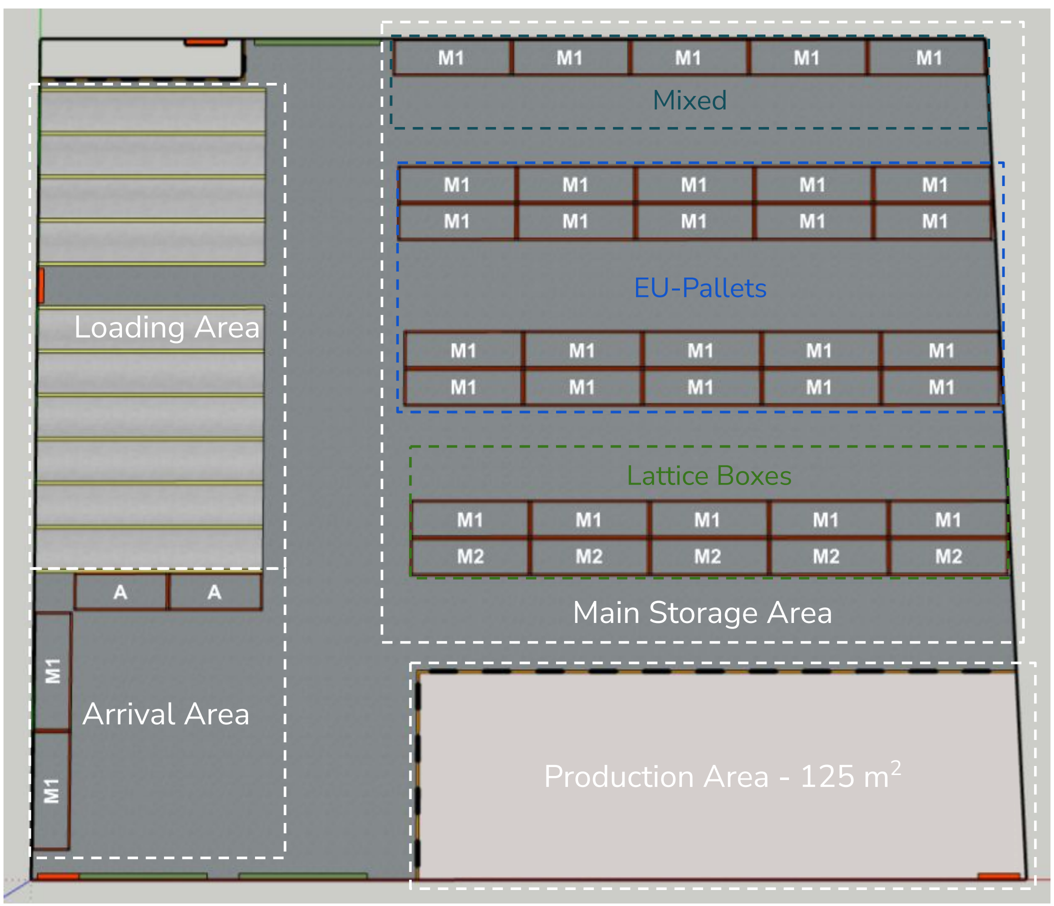

Figure 6.5: Conceptual design of the new warehouse layout.

Capacity
The arrival area has a total capacity of at least 84 SKUs. The floor storage bins have a capacity of 42 EU pallets or 50 lattice boxes. The area can also accommodate 42 EU pallets on the upper levels.

The main storage area has an aggregated minimum capacity of 892 SKUs. The upper levels of the main storage are dedicated to EU pallets and have a capacity of 400 SKUs. The floor storage consists of 240 floor positions for EU pallets, 180 for lattice boxes, and 72 mixed positions.

The loading bins have a total capacity of 150 EU pallets or 240 lattice boxes. The bins are five EU pallets or eight lattice boxes deep. The actual capacity on a given day, with a mix between the two, is consequently between 150 and 240, or 178 SKUs given the typical distribution of 66% EU and 33% lattice boxes.

The total capacity of the FGW aggregates to a total number of 1154 SKUs, given the typical distribution. The real capacity is, as described above, heavily influenced by the distribution of SKU types, as the SKU characteristics are significantly different.

Aisle width
The horizontal aisles between the production area and rows of M2, as well as between all rows of M1 and M2, are 3.0 meters. The aisle that passes through the whole warehouse is at its most narrow 4.2 meters, which is in the middle of the upper part of the staging area, where there are two M1-racks across the aisle. Due to the slope of the eastern wall, it is somewhat wider closer to inbound. The path that goes in between the staging area bins from the door on the western wall is 1.3 meters.

Outbound gate
The outbound gate has been moved from its location in the current FGW approximately 4 meters to the right, as can be seen in *Figure 6.5*. This was necessary to designate space for floor bins on the western wall above the door. The average distance from these four bins to the new gate is 10 meters. The door that is obligated to be situated next to the gate must also be moved, as can be seen in the figure. As the area around the door must not be blocked a no SKU-zone has been erected around it. The part of the zone that may contain things but is not appropriate for SKUs allows for storage of other equipment.

6.3.2.2 Storage Equipment

All racks will be configured to allow for floor storage of stacked pallets. Considering the dimensions of the racks and the SKU characteristics of EU-pallets and lattice boxes, racks M1 & M2 would enable storage of four respectively three and rack A three respectively two. The lattice boxes would however be stored two in depth. The characteristics of the three types of single deep pallet racks are presented in *Table 6.1*. Note that M1 and M2 are the same pallet racks but with different setups of different levels.

Table 6.1: The two different types of racks employed in the conceptual layout.

Pallet-rack	**Height**	**Depth**	**Beam length**	**Bar width**	**Max SKU weight**	**#**	**#SKUs**
M1	6000 mm	1100 mm	3600 mm	80 mm	500 kg	32	32
M2	6000 mm	1100 mm	3600 mm	80 mm	500 kg	5	32
A	6000 mm	1100 mm	2750 mm	80 mm	500 kg	2	32

M1 is very standardized and outlined to accommodate EU pallets with three pallet collars on the upper levels, which allows for three such levels above the floor storage. A M1-rack is conceptualized in *Figure 6.6*.

Figure 6.6: A M1-rack with fully utilized floor storage, and some SKUs on upper levels.

M2 is instead configured to be able to hold pallets with deviating height or width on the upper levels. A M2-rack is portrayed in *Figure 6.7*.

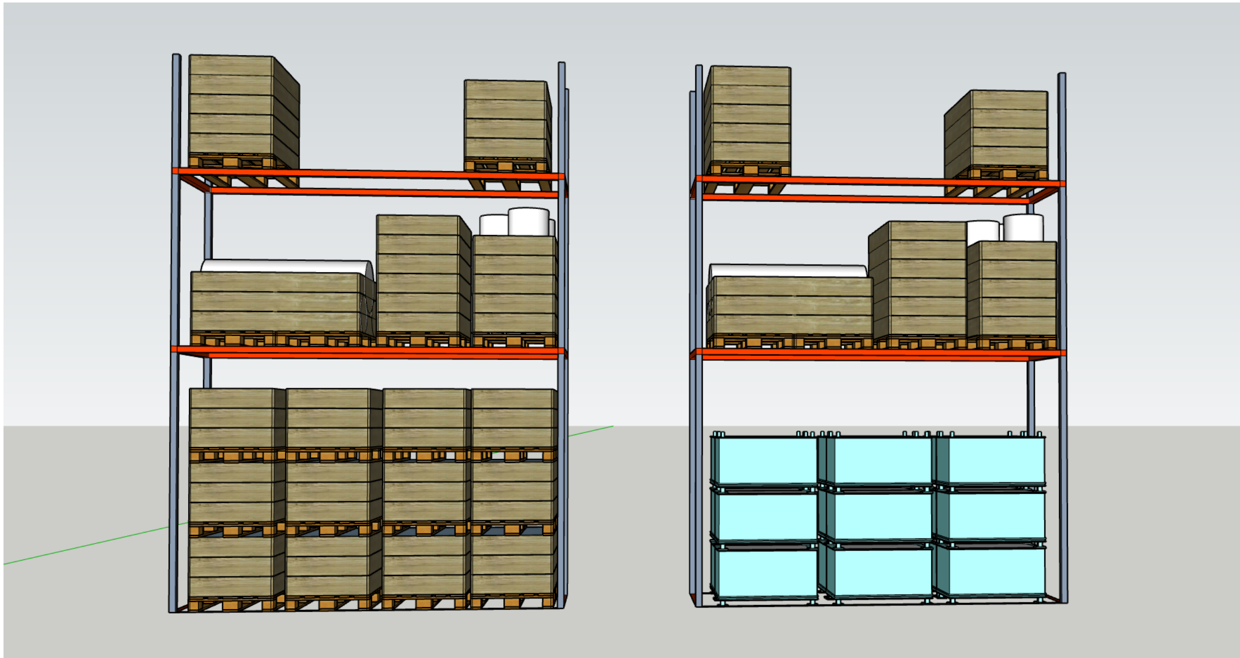

Figure 6.7: A M2-rack with fully utilized floor storage, and some SKUs on upper levels.

The A-racks are built to accommodate three collar EU-pallets on its upper levels. An A-rack is shown in *Figure 6.8*.

Figure 6.8: An A-rack with fully utilized floor storage, and some SKUs on upper levels.

6.3.2.3 Handling Equipment

The new configuration employs two reach trucks with full reach potential and one counterbalance truck. The above-mentioned aisle width in the horizontal aisles is sufficient for reach truck operations while the counterbalance truck is limited to loading, as suggested.

6.3.2.4 Automation & Information Systems

The main adaptation performed is utilizing the ERP system to keep track of all the pallet positions in the FGW and what they contain. The modified ERP system is interacted with through hand scanners and on-truck displays. The picking would be directed through an on-screen pick list instead of on a physical paper. These changes imply a change in the direction of more digitization and connectivity. The suggested configuration does not entail any new implementation or changes in the use of automation tools. For the repositioning in terms of automation vs digitization and connectivity see *Figure 6.9*.

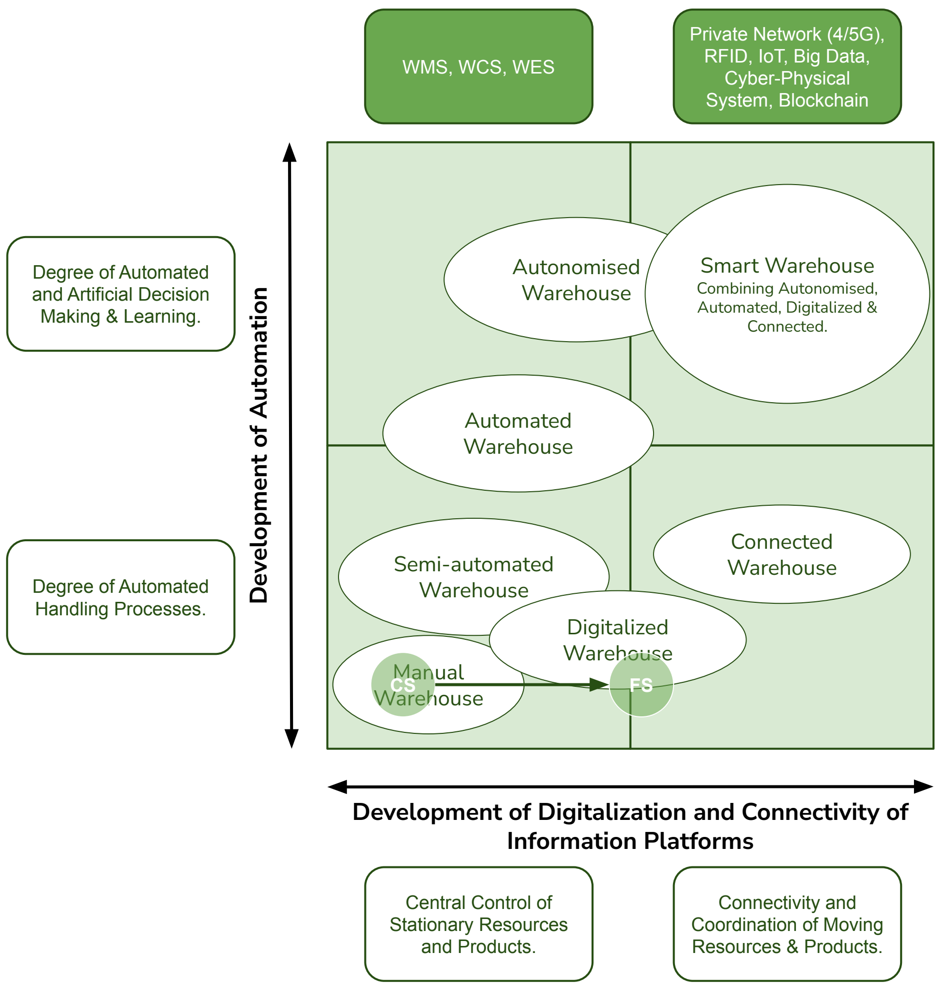

Figure 6.9: Repositioning of the Alfdex FGW in the automation matrix.

6.3.2.5 Labor & Safety

The new configuration affects the prerequisites for safety in labor and safety in several ways. As can be seen in *Figure 6.10* the flows in the warehouse have been increasingly isolated. The production workers transporting finished pallets to the FGW and retrieving additional material will never need to move above the A-racks. Simultaneously the warehouse operators only need to move below the line of A-racks to retrieve the finished pallets and occasionally access the yard. This means the flows are seldom crossed, even more so with the already limited amount of time that something is being moved in the warehouse. The production area can function without any notable risk of impeding on put-away or picking.

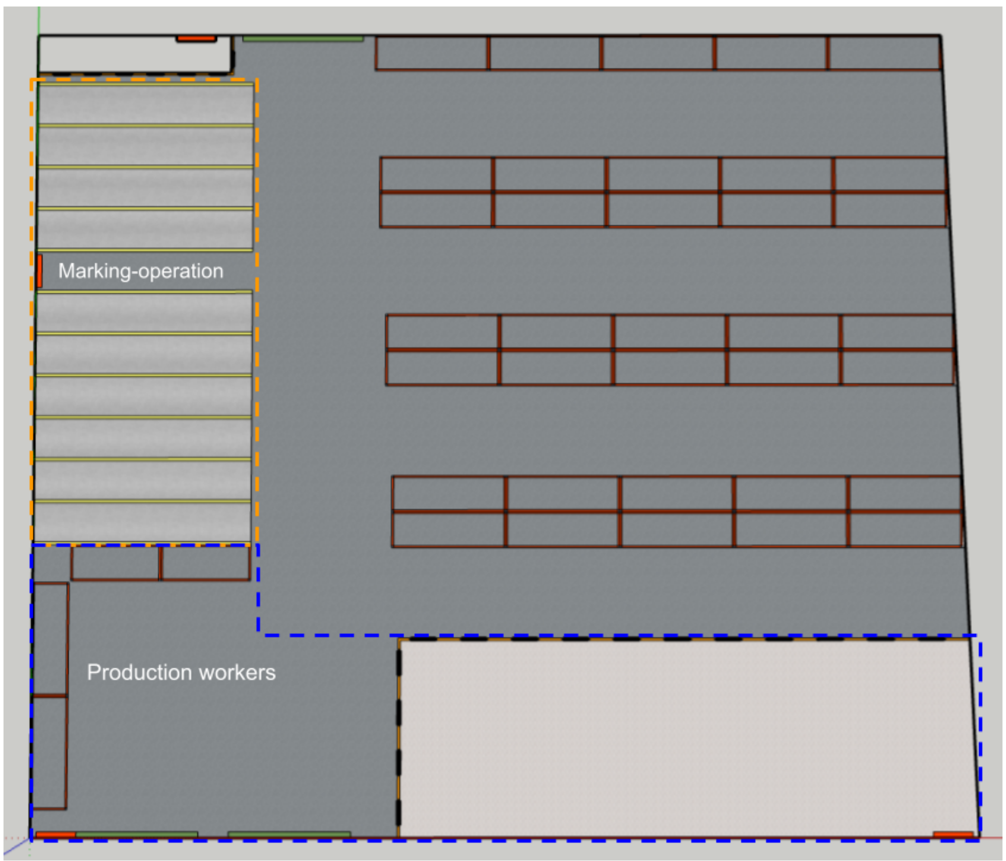

Figure 6.10: The FGW with supposed flows for warehouse workers and shipping personnel.

The process of marking the pallets, which is done to a whole day's worth of shipping once all pallets have been transported to the loading area, would also be isolated, hence decreasing the risk of injury. Shipping personnel operating would after entering through the western door only need to maneuver the loading area and the path between bins, as shown in *Figure 6.10*. During marking no picking or shipping of pallets is performed, which means the shipping personnel would never cross paths with warehouse workers in the FGW, which will improve both their safety and the warehouse workers feeling of a safe and easily maneuverable working environment.

6.3.3 Performance

Utilizing the same KPIs as determined in *Section 5.6* to evaluate the performance of the new configuration yields *Table 6.2*. Green indicates improvement while yellow means the value is unchanged. All values for operational times are collected from the updated VSM, see *Figure 6.4*. The high pallet face availability comes from employing single-deep pallet racks. The pallet position utilization comes directly from the number of pallet positions that are utilized on average.

Table 6.2: Key Performance Indicators (KPIs) for the new configuration

Category	KPI	Description	Unit	Value
Operations	Pallet-Flag Picking Time	Average time taken for pallet-flag picking	Minutes/day	0
	SKU Picking Time	Average time taken for SKU picking	Minutes/day	23
	Loading Time	Average time taken for loading	Minutes/day	5.3
	Total Operational Time	Total time taken for all operations	Minutes/day	82
Design	Pallet Face Availability	Percentage of pallets available without double handling	Percentage	100%
	Pallet Position Utilization	Percentage of utilized pallet positions in storage	Percentage	63%

6.4 Applicability of Configuration

This section of the report includes discussions on the applicability, assumptions, trade-offs, and future suggestions for the presented FGW configuration.

6.4.1 Warehouse Operations

The time for SKU-picking is expected to decrease, although the exact number is unclear. The average picking time for an SKU is expected to increase marginally, as some of the SKUs are stored on levels four to six in the pallet racks. However, the number of re-stacking pallets is expected to decrease, as the SKUs are not stacked randomly but by article. Thus, these effects are estimated to cancel each other out. Hence, it is deemed reasonable that the total time spent SKU-picking per day will decrease by 46%, which is the share of movement in the current SKU-picking operations that are classified as waste, as seen in *Figure 5.8*.

The new configuration will have a limited, or no, effect on most operations. The arrival process will be very similar to the current one, where SKUs are stacked on the floor and the bins are positioned similarly, which can be seen by comparing *Figures 4.10* and *6.5*. The same is true for the loading process, as the loading area has roughly the same, or slightly improved, location. The put-away process is expected to be affected, in the same manner as the SKU-picking, when dealing with levels four to six. However, this effect will be compensated for by the decrease in the average travel distance. By removing the emergent storage area, as can be seen in *Figure 4.10*, the forklifts no longer must go around it. Thus, our best estimations are that these effects will cancel out. The remaining operation is the marking, which will be completely unaffected as SKUs will be stored in the same manner in the loading area as now.

The changes made are largely changes that can be made, given the delimitations of the thesis. It is noteworthy that the operations in the FGW work reasonably well at present. That is, the time spent on operations and the system in general is fully functioning. This can be said from the fact that most operations, after investigation, will remain the same. Essentially, it is the picking operation is currently not functioning well. However, there is overall room for improvement. For example, the marking operation must be performed in close connection to the shipping process, as which SKU is sent to which customer is not decided until the day before shipping out. If the company decides to increase the freeze point to customers, the marking operation could potentially be made in the production. Which would render it more effective, by standardizing it, compared to being made by the shipping coordinators. To conclude, given the delimitations of the thesis, operations could unlikely be substantially further improved, without introducing other variables.

6.4.2 Warehouse Design & Resources

In terms of design & resources, it must be acknowledged that the theoretical space for arrangements that would improve the Alfdex FGW is significant.

6.4.2.1 Physical Layout

Arrival area

The arrival area will largely be like the current one, both in terms of location and capacity. The current arrival area, see *Figure 4.10*, is located directly to the left with five bins that are double deep, which renders a capacity of 30 bins. The updated area has 14 single deep stock locations, with a capacity of 42 EU pallets for SKUs arriving from production. Thus, both the number of locations and capacity have increased. However, one can wonder if all locations are necessary. The arrival area was designed to combat: (i) the fact that the warehouse workers only visit the area once per hour and (ii) that full capacity utilization is hindered, a change of production may lead to a single SKU taking up a whole stock location. However, by enhancing communication between production forklift operators and warehouse workers, through system support or verbally, to indicate when SKUs are ready for put-away, SKUs are handled faster, hence less capacity is required which frees up space. However, given the extensive changes of the new configuration, these smaller adjustments could be investigated further post-implantation. The main thought of isolating material flows will overall be improved as some additional material is kept in the arrival area.

Main Storage Area

The main storage has a similar layout, compared to *Figures 4.10 and 6.5*, but with a significantly increased capacity and structure. The use of a u-flow rather than flow-through, as seen in *Figures 3.4 and 3.4*, is suitable given the context. That is, with an arrival area close to the inbound, a loading area close to the outbound, and a cohesive production area, the location of the main storage area to the right was suitable. Many iterations of placing the main storage area were performed. For example, an alternative with a vertical rather than a horizontal main storage area, closer to a flow-through configuration, was investigated, and no good layout for all the areas was found. There are certainly other layouts that are as good, or better, given the context. However, this solution is sufficient for the main storage area, and a huge improvement compared to the current state, given the operations and capacity requirements.

Although it is claimed in the literature that a main feature of choosing U-flow is the skewed distribution of SKUs, which is true of Alfdex, the accessibility of the SKUs will be relatively similar in this case. Due to the FGW being small, traveling from the closest to the furthest stock location will not be a large difference in time. This fact supports our decision to use a random storage allocation policy, within the respective zone for the type of SKUs that are stacked at the bottom locations. Their operations could be further optimized by placing the SKUs with the largest demand at the best locations. However, the new configuration still brings several improvements. If the implementation is successful, small fine-tuning in the algorithm guiding put-away and picking can be made, to further optimize operations.

Loading Area

The loading area is designed with several constraints. The strategic location close to outbound aims to minimize loading times and reduce the stress of warehouse workers during simultaneous truck arrival. The last is due to Alfdex not having time slots as they never arrange the transport to the customer. Hence Alfdex also has little leverage to prevent trucks from arriving one day late, which when it occurs creates tremendous hassle. Moreover, the need for large space arises since the marking operation requires the SKUs to be at least half a meter apart. Furthermore, shipping varies greatly between days, as seen in *Figure 5.1.* The company aims to smooth out the differences, but their production is often behind schedule, which accumulates shipping to the end of the week. These factors combined mean that the loading area must be over-dimensioned and have over-capacity. This trade-off is necessary, by ensuring sufficient capacity the problems will not spill over to other parts of the FGW. Nevertheless, there is potential to drastically reduce the size of the loading area. However, this would require the implementation of measures such as freeze points, time slots, and improved production planning, which is outside the scope of this thesis.

The size of the loading area has changed, compared to the current layout. The current loading area, see *Figure 4.10*, is too small, as seen in the Heat Maps, see *Figures 5.9 and 5.10.* The new layout dedicates a larger portion of the warehouse to the layout, as seen in *Figure 6.5.* The main change is achieved by moving the outbound gate. Doing this enables multiple deep bins on the left-hand side of the FGW, in close connection to the gate. This in turn enables the aisles of the main storage area to be longer, towards the middle of the FGW, which increases the capacity per aisle. Moving the gate means an additional cost to re-configuring the warehouse. However, in comparison, the investment is relatively low compared to the total investment required for the total configuration. Initially, an alternative layout was created, using the current location of the outbound gate. However, it requires the loading area to be expanded further to the bottom, which significantly decreases the capacity and layout of the arrival area. Hence, the trade-off of moving the gate enables a significantly better FGW layout.

Production area

The area that should be allocated to the production area was never specified; it was rather asked for in the sense of freeing up as much space as possible while not under-dimensioning the rest of the warehouse. An earlier version of the configuration did nonetheless contain another double row of M1-racks, where the production area is now located. However, the benefit of more racks would be minimal considering the capacity is sufficient for now and the future predicted volumes. Here is an illustrative example of a trade-off, between capacity and space. Here our supervisor at the company, the logistics manager, opted for more space for the production area. What the area will be used for in practice is not entirely clear. Thus, the company must have a clear plan of what the production area should be used for, as they want to avoid having a new emergent storage area.

6.4.2.2 Storage & Handling Equipment

The introduction of storage equipment, in the form of pallets racks, is perhaps the most notable change in the reconfigured warehouse. It is perhaps also the most impactful in solving several issues such as limited capacity, double handling, and having dedicated storage locations to ensure FIFO. The last in combination with system support would enable total awareness of SKU whereabouts. The trade-off with pallet racks is the increased handling times when using the height. By storing most SKUs as stacks on bottom locations this problem is diminished. Another negative aspect is the need for concrete floors, which although cheap is another investment. The cost-saving does, however, more than make up for it over time. The time saved on operations, and retrieving lost pallets which are not quantified in the thesis, will make up for some parts of it. Additionally, the company occasionally uses an external warehouse, primarily for raw material SKUs, which could be placed in the FGW during peaks in the RMW, when the utilization in the FGW is not high.

The types of storage and handling equipment used are based on commercially available variants but adapted to suit Alfdex. The racks used for general measurement, for example, width and height, are available on the market. However, Alfdex may prefer a supplier whose racks have other measurements, affecting the capacity and layout of the main storage and arrival area.

The main idea behind proposing using storage and handling equipment, where ordinary reach trucks currently used in the RMW from their current supplier is included, is to use standard equipment to minimize costs. Nonetheless, Alfdex is advised to choose pallet racks that fit four EU-pallets in width for the main storage, corresponding to type M1 in *Figure 6.6*. In a four EU pallets wide rack, three lattice boxes can be fitted. On the other hand, only two lattice boxes fit in a three EU pallets wide. That is, "losing" 25% instead of 33% of the width.

To conclude, the choice of storage- and handling equipment would improve the FGW, at a low cost. This is important as the thesis is mainly driven by our supervisor at the company, the logistics manager, who drives the project of re-configuring the FGW internally. However, there are always trade-offs to be made, especially at a company level. Hence a crucial element is the cost of the new configuration. By choosing cost-effective elements, which will lead to large improvements, the trade-off scale is further tipped in the direction of investing.

6.4.2.3 Automation & Information Systems

The use of information systems in the reconfigured warehouse is crucial but to a large degree uncertain. To achieve important improvements with the new configuration, such as removing the pallet flag picking operation, streamlining the put-away and picking operations, ensuring FIFO, and increasing control over SKUs in the FGW, the information system plays an essential role. However, the company is currently in the process of investigating the current information system to potentially upgrade or change to another. Thus, it is hard to know what capabilities the future ERP system and potential WMS will have. Therefore, this thesis outlines the necessary attributes for the new system to ensure that the new configuration works properly. This is something the company can take with them as a prerequisite for the new information system(s) used if they choose to invest in the new configuration.

6.4.2.4 Labor & Safety

The safety and working environment have long been an overlooked aspect of the FGW. It originates from the decision not to insulate or lay a concrete floor when moving into the current facility although both the RMW and production part received those treatments. This is also why the FGW is renowned as the "cold storage", as it is the only place with temperature variations so heavily dependent on the season. Despite the bad forbearance of not choosing to implement the changes earlier, the increase in the number of SKUs since then as well as the potential gains in efficiency and the potential production area are convincing arguments. Additionally, the fact that similar processes have been completed for other parts of the warehouse is positive, as management is aware of the implementation course.

The problems with the FGW have been handled differently by workers. Warehouse workers have used the cabin of the counterbalance truck to address them. This would not be possible with the new configuration as the aisles are too narrow to allow for complete use of counterbalance truck throughout. However, not everyone has had this option previously either. Shipping coordinators have been particularly exposed to the poor environment. This is most clearly illustrated by the pallet flag-picking process, where they must crouch in dirty, tight, and poorly lit spaces between customer bins, making them hard to detect. Removing this process is a significant improvement. Even so, the need for a better environment remains, and insulating as well as upgrading the floor and lighting will improve the FGW's hospitality.

Implementing these changes is particularly important to facilitate parallel activity between the production area and production. Employees working in the production area would likely spend most of their time in the production part of the facility, where conditions are better. Ensuring good conditions in both areas can prevent the FGW production area from becoming a disliked assignment, which could lead to issues ranging from incorrect handling of pallets to carelessness when around active forklifts, impacting efficiency and safety respectively. As safety becomes a greater concern, clearly marked walking paths in the FGW are vital. Furthermore, with divided zones, wide aisles, and improved lighting, operations are less likely to be disrupted due to safety concerns of people crossing intended forklift paths.

6.4.3 Performance

Comparing the set of appropriate KPIs for the current and new configuration yields *Table 6.3*. As seen in the Value Stream Map, see *Figure 6.4*, the operational times decrease, and as a result, operational efficiency can be said to increase. To conclude the new configuration has a positive or neutral impact on all KPIs that were brought forward as suitable for the FGW.

Table 6.3: Key Performance Indicators (KPIs) for the new and current configuration respectively.

Category	KPI	Unit	New Configuration	Current Configuration
Operations	Pallet-Flag Picking Time	Minutes/day	0	58.5
	SKU Picking Time	Minutes/day	23	42
	Loading Time	Minutes/day	5.3	5.3
	Total Operational Time	Minutes/day	82	160
Design	Pallet Face Availability	Percentage	100%	20%
	Pallet Position Utilization	Percentage	60%	45%

In terms of the suitability of the KPIs, one must accept that KPIs never perfectly mirror the efficiency or reliability of what is being measured. The overall choice of precisely these KPIs could also be analyzed further as there are several factors to weigh in. One is how, as Parmenter (2017) states, KPIs should preferably affect some *critical success factor*, which it can be argued if any of the selected operational ones do considering the limited time that is spent on operations in the FGW overall. The relation between *Pallet Face Availability* and *SKU Picking Time* might also be too ”strong” for them to coexist as KPIs.

It can once more be noted that the values used, both currently through a set of measurements and for the new configuration through hypothesizing are uncertain. A practical perspective should also be added to the fact that it takes time for workers to get used to new operations and storage equipment. This can imply that the impact on the KPIs might initially be less, or even negative, to then increase over time until routines have been established. This is also when one can expect to see a surge in efficiency reaching the presented numbers.

7 CONCLUSION AND RECOMMENDATIONS

This section addresses the purpose and research objectives. It also conveys the contribution of the thesis, both practical and theoretical. Lastly, it addresses future research.

7.1 Fulfilling the Purpose

The stated purpose, to *propose a complete reconfiguration for the FGW at Alfdex*, has been fulfilled. Design propositions were developed, their implications for configuration elements explained and the reconfigured configuration, alongside its applicability, was presented in *Chapter 6*. To fulfill the purpose the research objectives have been achieved.

RO1: Understand how the warehouse configuration affects performance.

To understand how the warehouse configuration affects performance, a literature review and company visits were detailed in *Chapter 3* and *Sections 4.6 and 5.5*. The literature review explored the theory, presenting the contingency approach, where companies adapt their internal structures to contextual factors, by Lawrence and Lorsch (1967) and Donaldson (2001). This approach led to the use of the contingency framework for warehouse configuration, by Kembro and Norrman (2021), in which the structure of *Chapters 4 - 5* is based on. Configuration elements were studied using various sources, notably Bartholdi and Hackman (2019).

The company visits gave various insights. The visits of three distinct companies, presented in *Section 4.6*, allowed us to see how warehouse configurations were heavily affected by the different contextual factors. From the visits, the insights, presented in *Section 5.5*, had a large impact on the later development of the design propositions. It also provided us with guidance as to which contextual factors to investigate at Alfdex.

RO2: Investigate the current state of the FGW to identify wastes, contextual factors and requirements for new configuration.

The investigation of the current state at Alfdex is presented in *Chapters 4 and 5*. Here the analytical tools, presented in *Section 3.4*, play a crucial role. Activity profiling tools such as ABC-analysis and Heat Map are used to examine contextual factors, while lean tools like the VSM, SD, and MM are used to identify wastes under current contextual factors. The interviews provided a basis for examining a new configuration. The main identified requirements were following FIFO and including a production area.

RO3: Design a new configuration for the FGW and evaluate the expected performance.

The design of the new configuration and its estimated performance are presented in *Chapter 6*. The main step was to create the design propositions, outlined in *Section 6.1*, based on the literature review, empirical findings, and analysis chapters, integrating all relevant aspects. The implications for configuration elements of design propositions are shown in *Section 6.2*. The new configuration is presented in *Section 6.3*. The expected performance is assessed in the future state VSM, see Figure 6.4 and *Subsection 6.3.3*. This fulfills the purpose of providing a complete reconfiguration of the FGW.

7.2 Practical Contribution

The main contribution to Alfdex is the new configuration for the FGW, developed based on a thorough analysis of the current situation. The configuration addresses the issues concerning operations in the warehouse. The analysis itself was also a considerable contribution to Alfdex. The logistics manager, and other employees working in connection to the FGW, got an increased understanding of the current situation. Systematic mapping and the use of analytical tools brought an outside perspective on the current situation, especially since the staff and operations performed have remained static over recent years. Alfdex is anticipated to reconfigure their FGW soon, a process that the results from this thesis may influence or guide. While the proposed configuration may not be a perfect fit considering the ongoing investigations of other projects in the RMW and production area, the analyses and insights will serve as useful tools in finding a suitable future configuration.

Furthermore, the practical contribution also involves utilizing the company's key resource, the employees. Insights into the current situation were given through valuable interviews and observations of employees working directly with the FGW. The interviews functioned as a neutral forum where employees were encouraged to think beyond their usual tasks, identify challenges, and provide potential solutions. Several aspects of the new configuration stem from ideas shared by the employees. The process was mutually beneficial as employees gained insights but also were able to voice their thoughts and impact on the future work environment. The validation workshop at Alfdex, which all internal interviewees attended, provided an extensive overview of the current state of the FGW, in addition to allowing for direct feedback on the proposed configuration. We believe that the cross-functional approach of this thesis, involving individuals across departments, will improve the efficiency of operations as well as the working environment. We urge Alfdex to continue with this collaborative approach.

7.3 Theoretical Contribution

The main theoretical contribution is developing a reconfiguration for a production unit-load FGW, by highlighting contextual factors. As stated in the background section, how to reconfigure this specific type of warehouse is not well-studied in the literature. When designing a warehouse configuration, contextual factors are crucial, which has reoccurring been shown throughout this thesis. So, for readers finding themselves in the position to reconfigure this kind of warehouse, the thesis can be of use. However, several additional factors will impact how to develop the most appropriate configuration in each case. Thus, for readers who are investigating reconfiguring this type of warehouse, we stress that the reached configuration should not be used as a fixed template but rather as inspiration.

The methodology used to reach the new configuration is another significant theoretical contribution. The main part is the use of design science in research design, where several frameworks were utilized and combined. This heavily influences the development of our unique research process. Here, the use of company visits can be highlighted as a contribution. Investigating several companies is a method often used in multiple case studies.

Combining the contingency approach, design science and investigation of multiple companies leads to interesting synergy effects, which we have not seen in earlier instances, but we believe should be in the future. Additionally, the design process used was developed for the specific situation, of when to make which decisions, for designing a new configuration. Combining these approaches led to the methodological framework, which combined with the analytical framework led to the master framework for the thesis. The use of the master framework summarizes the content of the methodology and frame of reference chapters, which is something we believe future master theses could benefit from adopting.

Furthermore, the use of CAMO for design propositions and the thorough investigation of their implications is another theoretical contribution. Applying the CAMO format to formulate design propositions was something not found before in the literature. The link between CAMO and design science has thereby been reconfirmed. During artifact development, it was aspired to be transparent and make it easily understandable. Thus, the design propositions were explained thoroughly, and their implications for configuration elements outlined, before presenting the new configuration. The approach has a clear trade-off, for while being transparent and thorough it can become repetitive. This thesis has a transparent and rigid design process, which future research can recreate or learn from.

7.4 Delimitations & Future Research

The main delimitations are the ones concerning writing a master thesis. The thesis has a timeframe of 20 weeks which directly limits the scope, and level of detail, to be investigated. A longer project would permit the analysis, both in level of detail and number of tools used, further development. For a concrete example of analysis investigating stock levels, where only a few articles are included, see *Figure 4.1*. By investigating the articles constituting 85% of the volume, and compensating for the last 15%, a satisfactory analysis for the thesis was reached. However, it could have been more exact if the time had allowed. Additionally, there were several aspects of the solution that were not investigated. This included a strategy, and cost of investment, for implementing the configuration. Furthermore, there are plans for other parts of the Alfdex site, specifically the production area and RMW, which will affect the FGW configuration. Thus, the implementation, in combination with other projects, is something that could be researched in a future master's thesis.

There is also a clear limitation in the generalizability of the thesis. This project investigates one part of one company with a specific process. As mentioned, the thesis could serve as inspiration for those about to reconfigure a production unit-load FGW, or similar. However contextual factors must be considered, and this solution is only one out of many suitable for these. This holds for the new configuration but also the methodology. Thus, we would like future researchers to generalize the findings in the thesis in other instances. This included the design process, CAMO format for the design propositions as well as the use of the methodological- and master frameworks. We believe that using, and improving, these elements will be a valuable addition to future master theses.

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Appendix A - Interview Guide for Alfdex Employees

Introduction:
- Who we are and what we are doing.
- Describe the thesis project and the contingency framework for configuration.
- The purpose/goal of the project: To design a new configuration.
- What you will contribute with:
    - YOUR perspective, in terms of:
        - how well the operations work today.
        - problem detection and ranking.
        - improvement suggestions for the future.
- Answers will be anonymized in the report, only the title will be presented.

Roles and assignments:
- What is your role?
- Can you provide an overview of your primary responsibilities in connection with the FGW?
- What specific tasks do you perform daily as part of your role?

Operations:
Depending on the position, the interviewee will describe different processes in the operations.

Truckdriver - Show and describe the put-away process in detail.

Shipping - Show and describe the picking, of "pallet flags", process in detail.

Goods-reception-employee (1st shift) - Show and describe the loading process in detail.

Goods-reception-employee (2nd shift) - Show and describe the picking process in detail.

Resources:
- If you use the WMS, in what way do you use the WMS?
- If you use the forklifts, in what way do you use the forklifts?
- How much do you use these resources daily?

Problem identification:
- Describe the problems that you experience in connection with the FGW configurations, this includes both operations as well as Design & Resources.
- For each problem:
    - A detailed description of the problem
    - How large is the impact of the problem on your day-to-day tasks?
    - How long is wasted each day on the problem?
    - In total., rank the severity from 1 - 5 (low to high).
    - What do you think could help solve the problem?
- Do you have any other improvement suggestions for the FGW?

Appendix B - Interview Guide for Company Visits

Company Profiling

Company:

- What does the company produce?
- Is the product sold to businesses or individuals?

Warehouse:

- How large is the FGW? (approximate dimensions)
- Are the entrance and exit on the same, or opposite, sides of the warehouse?
- How many pallet positions are available in the warehouse?
- How many of the pallet positions are utilized?
- How many employees work, during a shift, in the warehouse?
- What types of SKUs are stored?
- What is the daily flow, in terms of the number of SKUs, in and out of the warehouse?
- Are there any dedicated temporary storage spaces for incoming and outgoing goods?

Operations:

- What types of transportation occur in FGW? (for example, put-away, picking, sorting, loading)
- What storage strategy is used? (for example, dedicated, shared, etc.)
- What picking strategy is used? (for example, transversal., return, etc.)

Design & Resources:

- What types of trucks are used in FGW? AGVs and/or conventual trucks?
- How are SKUs stored? Pallet racks or other?
- How are the aisles designed? (for example, cross aisle, fishbone)
- What warehouse management system is used? (for example, ERP, WMS)

Interview questions

Warehouse:

- What is the main purpose of the warehouse? (for example, lean, high availability, fast picking)
- Could you identify two strengths and weaknesses of the FGW?
- What problems have you encountered that you have subsequently resolved? How did you go about solving them?

AGVs (if AGVs are used):

- When were AGVs implemented? Why?
- In what operations are AGVs involved?
- How did the implementation work? What were the biggest challenges?
- How are AGVs controlled? Is it a separate system or through WMS (Warehouse Management System)?
- What problems are currently associated with AGVs?
- How do you evaluate your AGVs?

Conventional Trucks (if AGVs are not used):

- How are workers directed in their work? (for example, picking a list with route description)
- What considerations did you have when choosing forklifts?
- How do you evaluate the forklifts?
- Have you explored the possibility of acquiring AGVs?

  If no

  - Why have they not been investigated?

  If yes

  - Which type of AGVs was explored and in what operations?
  - Which information system was used to control them in the investigation?
  - What decision did the investigation result in?
  - What parameters were looked at to make this decision?

Performance Measurement:

- How do you measure the performance of the FGW?
- Do you use KPIs? If so, which ones?

Appendix C - Trucks

Figure 7.1: Counterbalance truck. *Photo credit: Toyota Material Handling, Inc*

Figure 7.2: Reach truck. *Photo credit: Toyota Material Handling, Inc*

Figure 7.3: Double reach truck. *Photo credit: Toyota Material Handling, Inc*

Figure 7.4: Turret truck. *Photo credit: Toyota Material Handling, Inc*

Appendix D - Current Warehouse Designs

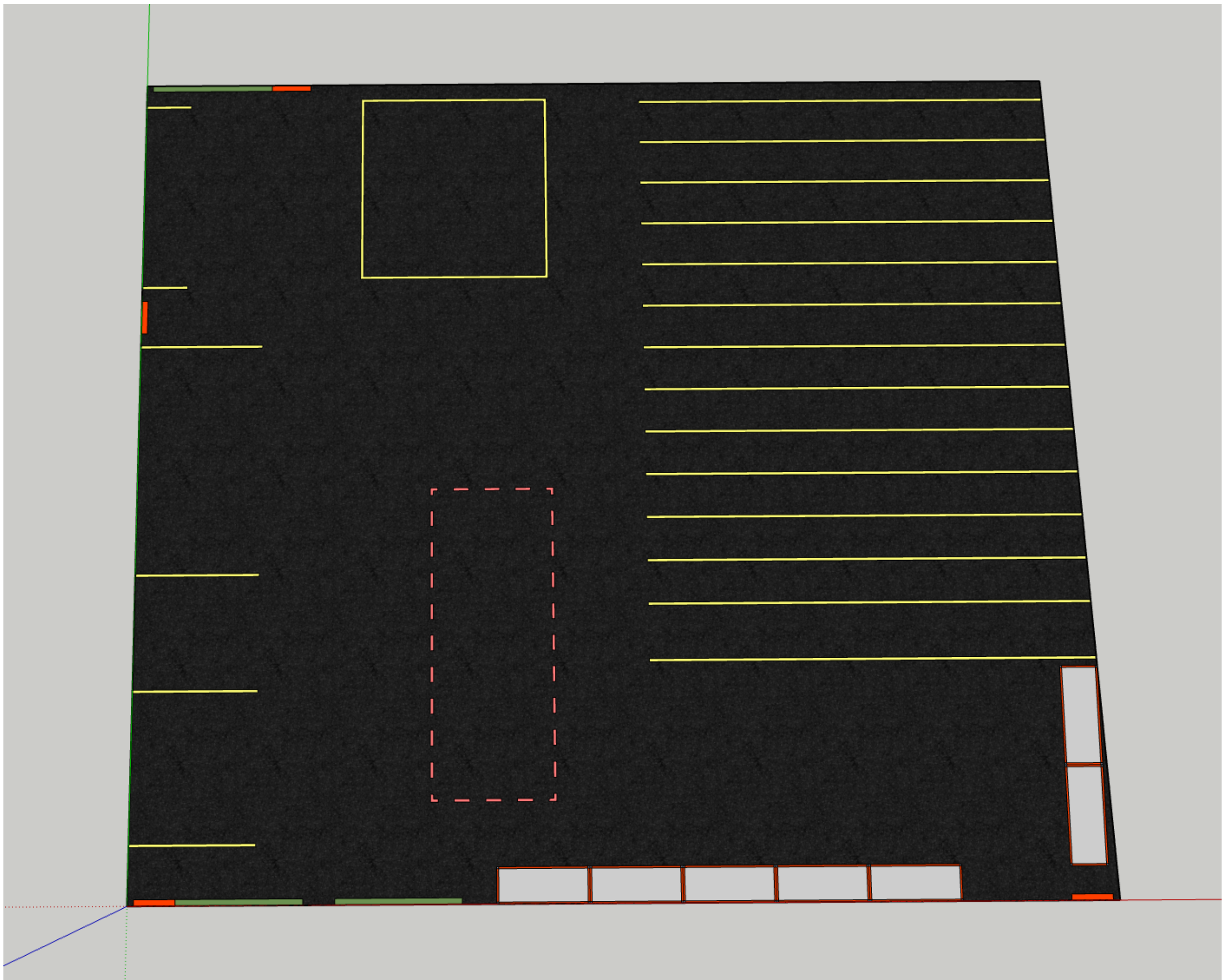

Figure 7.5: Current Alfdex FGW designed with actual measurements using Google SketchUp.