DESIGNING A NEW WAREHOUSE TO IMPROVE SPACE UTILIZATION AND HANDLING EFFICIENCY

A case study of a production warehouse

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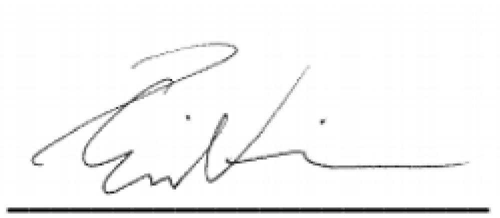

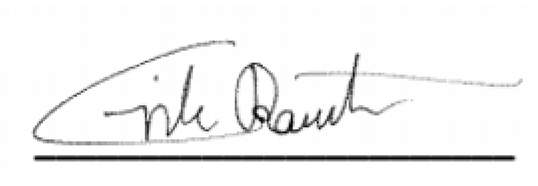

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Lund, May 2021

ABSTRACT

Title: Designing a new warehouse to improve space utilization and handling efficiency: A case study of a production warehouse

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Problem description: The focus on warehousing has grown in the industry during the 21st century to increase the competitive advantage of companies. Despite this, the development of the coil warehouse at Alfa Laval has received little focus during the last decades. This is in contrast to Alfa Laval's goal of following global industrial development.

Purpose: To close this gap, the purpose of the thesis is to provide two recommendations of how the production warehouse of coils can be designed to increase space utilization and make the handling process more efficient.

Objectives: The recommendations to Alfa Laval are provided through fulfilling the objectives of the thesis. The first objective is to describe the current situation to get an understanding of the processes needed and which changes that are suitable. The second objective is to identify the challenges with storage of coils to know what the new solution should be able to solve. The third objective is to identify the contextual factors to take the unchangeable parameters into account. The fourth and final objective is to identify suitable configurational elements which the final recommendations will be based on.

Methodology: The method used in this thesis is the case study which consists of analyzing the problem in the context of a case company, Alfa Laval. The case study began with a literature review to understand what previously had been written about warehousing. Following this, the current situation at Alfa Laval was mapped through observations and interviews of employees as well as data extraction from information systems. Finally, the collected data was analyzed to identify the suitable configurational elements which were combined into two recommendations.

Conclusion: The result of the thesis is two recommendations which both decrease the majority of the identified challenges. Both of the recommendations have the same changes in the operations with a movement of the quality inspection and unpackaging from the picking phase to the receiving phase, to make it possible to pick directly to the production, and with an introduction of more structured picking and storage policies. The storage of the first recommendation is to use cantilever racks and to store the coils without pallets. The second recommendation is to automate the picking and put-away process through installation of an overhead crane with the coils stacked on the ground without aisles.

Keywords: Warehousing, warehouse design, production warehouse, contextual factors, space utilization

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ABBREVIATIONS

AS/RS - Automated Storage and Retrieval System

ERP - Enterprise Resource Planning

FIFO - First In First Out

FMCG - Fast Moving Consumer Goods

KPI - Key Performance Indicator

LIFO - Last In First Out

PA - Packaging Area

QR - Quick Response

SKU - Stock Keeping Unit

WMS - Warehouse Management System

YS - Yard Storage

1. INTRODUCTION

1.1 Background general

The 21st century has brought a change to the markets with an increased level of uncertainty, competition being stronger between companies, products having shorter life cycles, unspecified demand, and a more unreliable supply (Rimienė, 2011). With products becoming more and more similar between competitors, it is no longer possible to maintain competitive advantage solely by aspects such as price and product differentiation (Vieria and Leite, 2016). To stay competitive there is a need for increased efficiency of delivering the right product at the right time. Rouwenhorst et al. (2000) argues that the efficiency and effectiveness in any distribution network is determined by its nodes, the warehouses. The importance of a well-designed and effectively managed warehouse is also emphasized by Rushton et al. (2014), as the way they operate has an immediate impact on both customer service and costs. Warehouses can represent up to a quarter of the total logistics costs (Rushton et al., 2014; Baker and Canessa, 2009) and have previously been regarded as a costly burden (Bartholdi and Hackman, 2010). This view has changed, and warehouses are increasingly seen as a strategic component (Kembro et al., 2018).

Warehouses play a crucial part of any supply chain and can have many different roles (Gu et al., 2007). The roles can have purposes such as matching supply with customer demand, to consolidate products, enabling postponement, or as a cross-docking center, where products are directly transferred from an incoming to an outgoing vehicle (Bartholdi and Hackman, 2010; Rushton et al., 2014). The warehouses can also differ in terms of types, either as an e-commerce distribution center, receiving small orders but at great numbers, or as a production warehouse, storing goods associated with a manufacturing process (Batholdi and Hackman, 2010; Rouwenhorst et al., 2000). Despite these differences there are also similarities. The operations within a warehouse can be divided into inbound and outbound processes. Inbound operations are receiving and put-away while outbound operations are picking, packing, and shipping (Bartholdi and Hackman, 2010).

In order to manage the operations efficiently and effectively it is important to consider the resources of a warehouse and how these are designed. These aspects include aisle orientation, level of automation, storage strategy, material handling equipment, and labor (Rouwenhorst et al., 2000; Gu et al., 2007). Together with the operations, these aspects are seen as the configural elements of a warehouse (Kembro and Norrman, 2019). With the performance of a warehouse being partly determined in the planning phase, creating the appropriate warehouse configuration requires all elements to be considered from the start (Baker and Canessa, 2009; Rouwenhorst et al., 2000). The literature has discussed using the contingency approach to increase the performance. This approach suggests that structures and processes, i.e., configural elements, are matched with their environment, also referred to as its contextual factors (Kembro and Norrman, 2020). Purpose of the warehouse, product and order characteristics, and market condition are factors that can fluence warehouse design (Kembro et al., 2018; Rushton et. al., 2014). Common between all contingency approaches is that the performance is a consequence between structure and context (Faber et al., 2018).

In the identified literature, it is of the authors knowledge limited research that has covered this area in relation to raw material warehouses with standardized Stock Keeping Units (SKU), which have little variation and unitized handling type. This thesis is therefore put into context by using a case company that exists in this setting.

1.2 Background of case company

To be able to put the research in context, Alfa Laval has been chosen to be the case company of this thesis. Alfa Laval is a world leading company within their three technologies of heat transfer, separation, and fluid handling. They began their work with the separation of dairy products in 1883 and started with the heat transfer through heat exchangers in 1938 which nowadays is the product with their largest market share. (Alfa Laval AB, n.d.b) One reason behind the success with the heat exchangers is that the technology is essential in many industries resulting in a larger market with a greater need. Another reason is that the focus on developing first class technologies has resulted in plate heat exchangers which are among the most cost-effective on the market (Alfa Laval AB, n.d.a). In addition to their success based on their technology development, Alfa Laval also strives for success through high performance within customer service. The products should be delivered on time and if something happens the customer will receive the spare parts and service needed in a timely manner. (Alfa Laval AB, 2020)

One of their production sites of heat exchangers is located in Lund, Sweden, which is also where their headquarters is located. The thesis will have a focus on the production warehouse of coils at this factory. The heat exchangers consist of many metal sheets separating where the cold and hot fluids flow and it is through these plates the heat transfers, which can be seen in Figure 1.1. The plates are produced at site in Lund from metal sheets, which are stored in coils, and get punched to the right pattern. It is the warehouse storage of these coils which will be in focus of this report.

The existing working method at Alfa Laval is not reflecting the global change of viewing warehouses as strategic components (Kembro et al., 2018) nor is it in line with their strive for high customer service. Many companies use a Warehouse Management System (WMS) to know in what quantities and at which location a product is stored. (Lam et al., 2010). When it comes to Alfa Laval, they only recently introduced a Quick Response (QR) system to facilitate the positioning of the coils. Prior to this there was no location system in place. Beyond this implementation the working method has been the same for many decades and the warehousing has not been given much attention.

The next step in their development of the coil warehouse is to take a big leap towards a more effective and efficient flow. The aim is to replace the existing two tents and the open yard storage with a single new warehouse facility. The design of the warehouse, which method, and which technologies to implement are some questions this thesis will discuss.

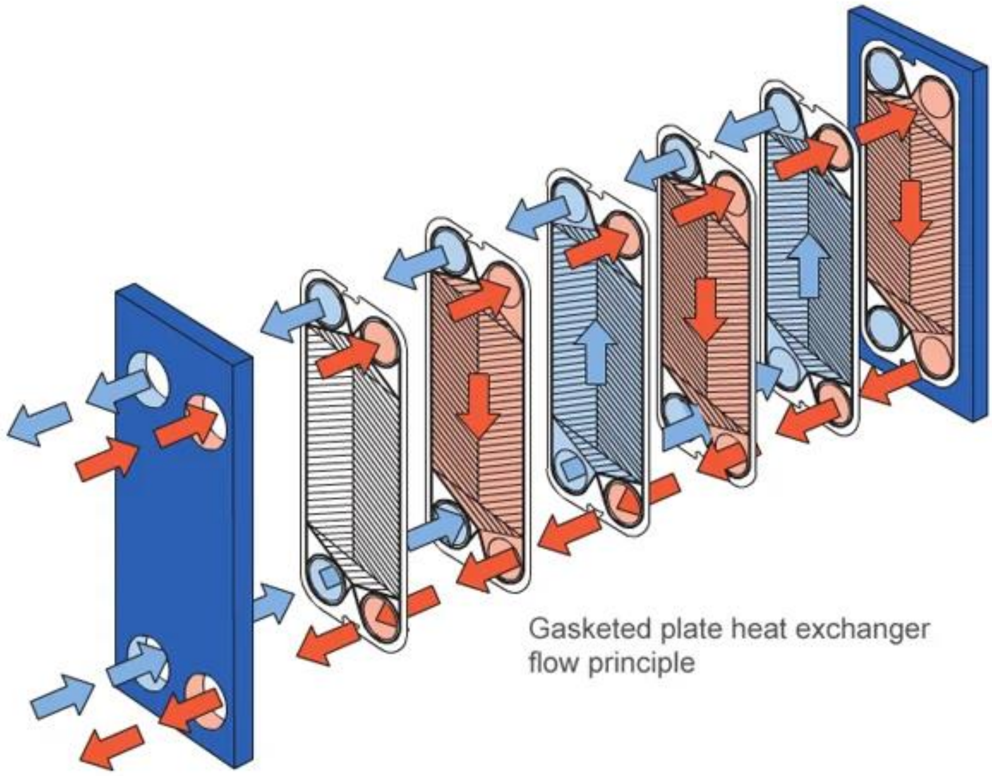

Figure 1.1 - Illustration of a heat exchanger which has the sheets produced from the coils in the middle. (Alfa Laval AB, n.d.c)

1.3 Problem formulation.

The existing setup of the warehouse neither matches the development of warehouses in general nor the goal from Alfa Laval (Alfa Laval AB, 2020). The setup and working method have been almost the same since the 1970s which shows that something has to be done. The result of storing the coils outside, both in tents without heat and open in the yard, is that the coils need to acclimatize in the warehouse inside the production facility for 24 hours before they can be used. This is a result of the changing properties of metal with different temperatures and to get rid of the condensation between the layers in the coil. The extra time added to just acclimatize the coils is a non-value adding activity. This setup of warehousing also results in a lot of double-handling, which also is a non-value adding activity and should be avoided.

Another time-consuming activity is the transportation of coils from the storage to the production. Because of the placement of the tents and the coils in the yard there is a lot of time spent on just transporting the coils. The majority of the coils are stored on the ground in around five pallet deep lanes. This placement and the lack of localization of where the coils are stored results in much time of just locating the right coil. The low space utilization is, in addition to the ground storage, lowered even more because of the wide aisles needed for the large trucks used for transportation.

1.4 Purpose and Objectives

The purpose of the thesis is to provide Alfa Laval with two recommendations of how the production warehouse of coils can be designed to increase space utilization and make the handling process more efficient. The reason behind the new design of the warehouse is that the development is lagging behind, both compared to the warehousing in general but also when it comes to the internal goal of the development of the supply chain at Alfa Laval. The recommendations will include different scenarios based on time horizon, technologies to include, and total cost with more. There are four objectives that will make it possible to fulfill the purpose of the thesis.

Objective 1: Describe the current warehouse configuration

The first objective is to describe the current situation of the warehouse at the case company. This will include a detailed description of the current operations, design and resources.

Objective 2: Identify the challenges with storage of coils

The second objective is to identify the challenges with the storage of coils. These challenges can be identified through the description of the current configuration, which in turn is based on observations, interviews, and data from information systems, and is something the final proposal will reduce.

Objective 3: Identify the contextual factors for Alfa Laval

The description of the current situation will make it possible to identify which contextual factors that exist at Alfa Laval. In this context, these factors are not possible to affect and have to be considered within the new proposals to make sure they suit the circumstances.

Objective 4: Identify suitable configurational elements in this context

The final objective is to identify suitable configurational elements which are supposed to solve, avoid, or minimize the possible challenges that were found and are adapted to the contextual factors. These configurational elements will be combined to result in two warehouse configurations which will be presented as recommendations to Alfa Laval which in turn fulfills the purpose of the report.

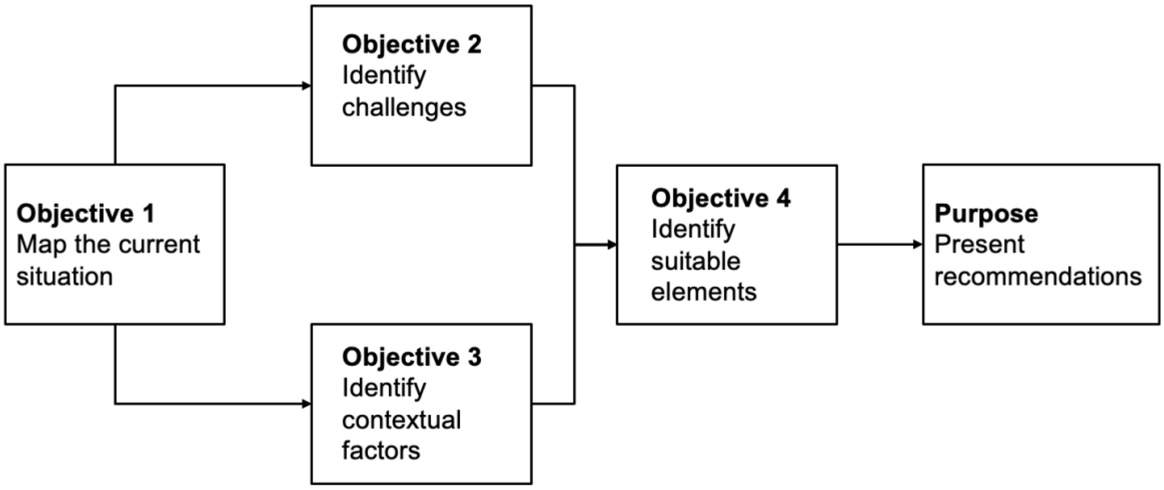

Figure 1.2 - A visualization of the connections between objectives and purpose

1.5 Delimitation

This study will be focused on designing a new warehouse, to store coils, with a focus on reducing the identified current challenges with regard to the existing contextual factors. Activities such as ordering, inventory control, deliveries from suppliers, designing of the building beyond the size, and a detailed mapping of the layout will be excluded. The scope of operations covered in the thesis will be from retrieved goods to the picking of coils to the production, see Figure 1.2.

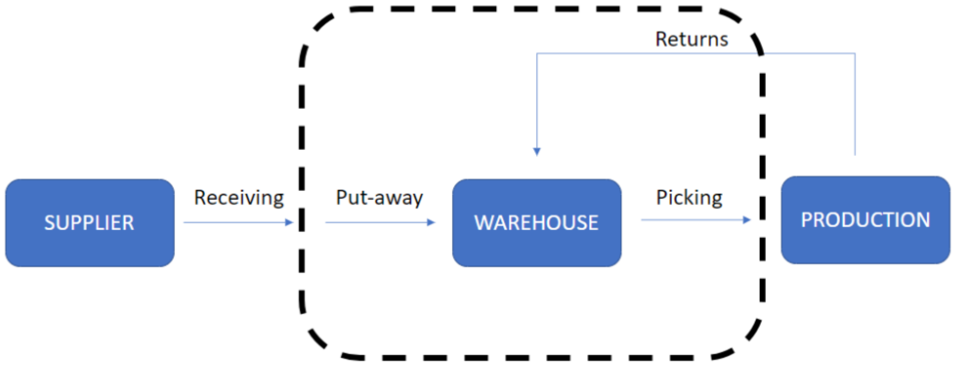

Figure 1.3 - Scope of the study

The recommendations will include areas such as how the overall operations should be conducted. The recommendations also include which equipment that should be used and how the physical layout should look like, as well as a specification on what functions that the information systems need to have. The changes of performance at Alfa Laval are linked to the implementation and change management but will however be excluded because it is not connected to the purpose. Because of the time scope of this thesis, 20 weeks, and that it is a new design and not a redesign, many areas will be included but only generally.

1.6 Structure

The report consists of seven chapters which all have their own purpose. The first chapter consists of a background of both warehousing and the case company as well as an explanation of the purpose of the thesis and the delimitations. The second chapter, methodology, describes how the research was executed to increase the validity and reliability of the report. The third chapter, the frame of reference, provides a foundation of theory regarding warehousing. This will assist the authors in both understanding which data that needs to be collected as well as what decisions that need to be taken when designing a new warehouse. The fourth chapter is where the current situation is described to see the processes and the existing challenges within the warehousing of coils. Chapter five analyzes how the identified challenges can be reduced with help of the theory. It is also here the contextual factors are identified which the recommendations have to be adapted to. The sixth chapter is where the most suitable and final recommendations are presented from the configurational elements in chapter five. Finally, the seventh chapter is where the answers to the purpose and objectives are summarized and areas suitable for future research are presented.

2. METHODOLOGY

The methodology that will be used throughout the thesis consists of five sections, which is shown in Figure 2.1. The first section is the selection of the research strategy that suits this thesis best. The second section is to provide a design of the procedure of the thesis, how the different tasks are connected, and in which order they should be done. The third section is connected to the collection of data, how it is collected and what type of data it is. The next part includes how the analysis of the collected data should be performed to enable a better result. The final section concerns how the whole research should be done to increase the reliability and validity of the result.

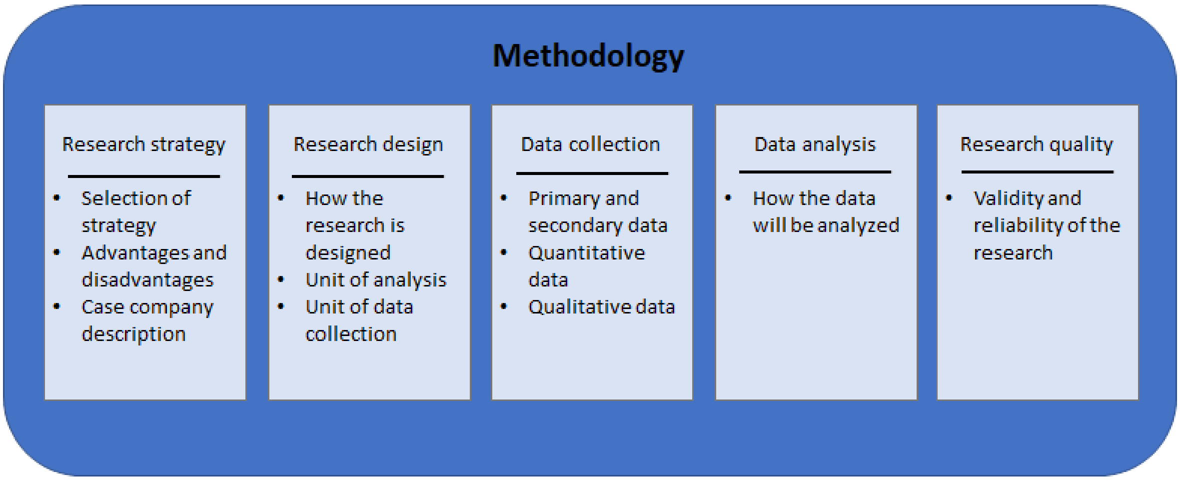

Figure 2.1 - Visualization of the methodology chapter

2.1 Research strategy

The research strategy guides the project in decisions on what data to collect, how it is collected, and the selection of the right research objectives. There are several methods to choose from and the selection of one that suits the purpose of the research will facilitate the collection of the right data to answer the research objectives. But the selection of research strategy also depends on the previous knowledge within the field, the time restrictions, and the other available resources. The most important thing is not what the method is named but how it is used, which means that there is no need to follow the models to the letter. (Saunders et al., 2007)

The case study was the method which suited the purpose of the thesis the most because the main question was how the warehouse could be designed. This was also strengthened through the fact that the case study is one of the most powerful methods to use when the problem is about operations management (Voss et al., 2002). Despite being a popular research strategy there are many cases where the report becomes more of a consultancy report, which was not the purpose of this thesis. The reason for this risk is an absence of discussion, which data that was collected, and how the analysis of the data and validation of the result was done (Stuart et al., 2002). How these pitfalls were avoided is presented later in this chapter of methodology.

2.1.1 Advantages and disadvantages

The major advantage of using case study as a research strategy is that it enables the phenomenon to be studied in its natural setting (Meredith, 1998; Flyvbjerg, 2006). This provides an in-depth view of a real-life example so that detailed and relevant data that is taken in context can be obtained. Other advantages of using this method are that it facilitates in answering questions of a *how* character where the researcher has little or no control over the events, as well as enabling different data collection methods (Yin, 2018).

One disadvantage relevant to the case is that the status of the report will, according to Yin (2018), be lower than if other strategies were used. But the result comes from prejudices that case studies only are the first step in research and that other strategies are higher in the hierarchical order when it comes to reliability. The real situation according to Yin (2018) is that the result is equally valuable and reliable as other strategies which means that this disadvantage is more of a moral disadvantage and does not affect the actual research. Other disadvantages are that the process takes time and can be inefficient (Meredith, 1998). These disadvantages affected the process of the research, especially since it had a time constraint of 20 weeks. Even though there are some disadvantages with the case study method, the advantages outweigh the disadvantages which confirms that the choice of case study was the preferred way to go.

2.1.2 Case company

Alfa Laval, originating from the fluid handling and separation business in the 19th century, began manufacturing their first heat exchanger in 1938, which since then has grown to represent 40 % of their total sales. The last 10 years the case company has achieved close to 100 % increase in turnover and this upwards growth trend can be seen in Figure 2.2 below.

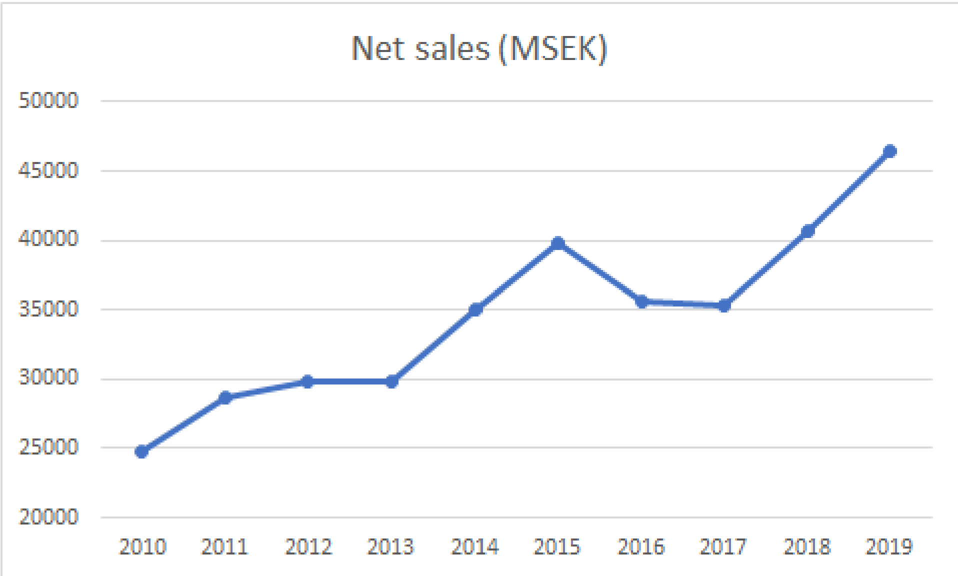

Figure 2.2 - Net sales history, based on Alfa Laval AB (2020)

The factory in Lund produces the complete assortment of heat exchangers and therefore stores a variety of metal coils to support the manufacturing. The general growth trend of the company is not reflected within the warehousing development. Currently, Alfa Laval is storing the components in two different tents, without heating, located across the yard at the factory. Inside the tents the coils are mainly stored by floor storage and with a few being stored in racks. The lack of space has also resulted in a number of coils being stored outside the tents, as well as openly in other areas of the yard. With a lack of heating in the storage areas the coils are also required to be temporarily stored in an area close to the production to acclimatize before they can be used. Overall, the warehousing situation has seen little development for several decades. Only recently there was a location tracking system implemented, where QR-codes are used to track the storage of coils.

To accommodate the development of the company, there is currently a plan for a complete production revamp, a change within warehousing is needed. The space and handling efficiency seeks to be improved by building a single new warehouse to replace the current setup. The case company is a good match for this thesis by providing an opportunity for literature contribution within a scarce area of contextual factors, production warehousing with standardized SKUs.

2.2 Research design

After the research strategy has been selected, the next step is to design the research procedure. The procedure, which can be seen in Figure 2.3, describes which steps were taken and in which order to facilitate the research process.

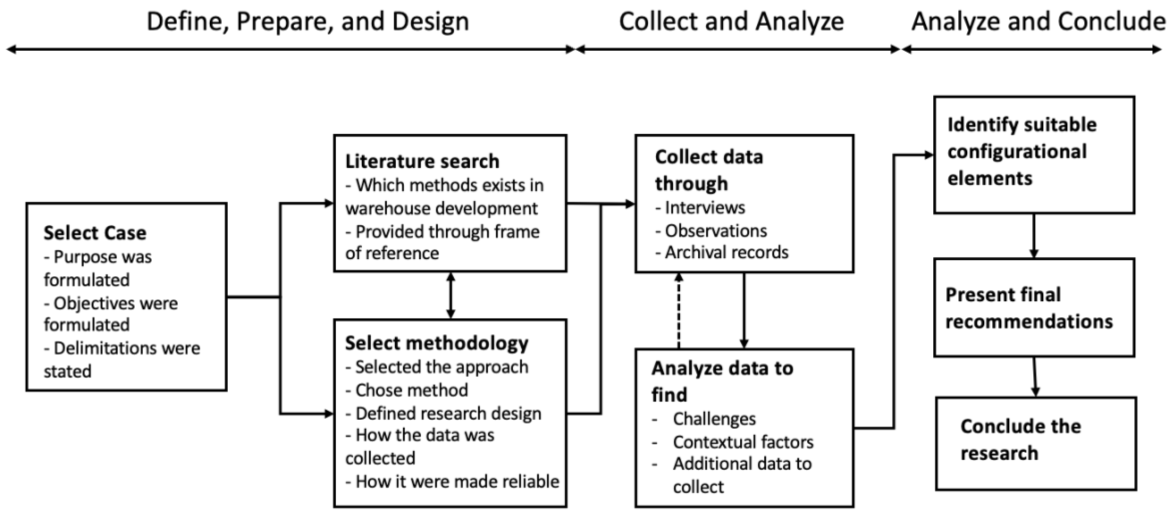

Figure 2.3 - The research design, inspired by Yin (2018), and Kembro and Norrman (2019)

2.2.1 Unit of analysis

When a research is conducted it is important to have a clear picture on what the unit of analysis is, otherwise it is a risk to start with e.g., a survey strategy instead of a case study because of how the data collected is analyzed (Yin, 2018). In this report the purpose was to design a warehouse. Connected to the warehouse design one of the objectives was to identify the contextual factors of this situation. Therefore, to get the unit of analysis both of these were combined and resulted in a *contingency of factors influencing the warehouse configuration.*

2.2.2 Unit of data collection

The difference between the unit of analysis and the unit of data collection is that the former determines what should be found while the latter regards how the data that will be analyzed is collected. But a similar problem as with the unit of analysis could occur according to Yin (2018). If the case study has a unit of analysis about an organization and all the data is collected from interviews about the organization the whole project turns to survey research because all the data was from the same unit of data collection. To avoid this situation and keep the research strategy as a case study the unit of data collection was determined to be, inter alia, interviews with employees from both the office and the production about the organization, quantitative data in the form of history of the flow of SKUs, and observations of the current situation.

2.3 Data collection

This research included multiple ways of collecting data throughout the project. The data was collected through observations of the existing warehouse and processes, interviews of employees working in both the warehouse and in the office, archival records from previous experiences and courses, the flow of coils through history and the forecasts, and journals and books to get the needed information about methods and approaches that were used. From the collected data the analysis was conducted which resulted in recommendations on how to proceed with the development of a new warehouse. An overview of the data collection can be seen in Figure 2.4. The different types of data could either be collected qualitatively or quantitatively and either from a primary or secondary source. How the different data was categorized is explained in the following subchapters.

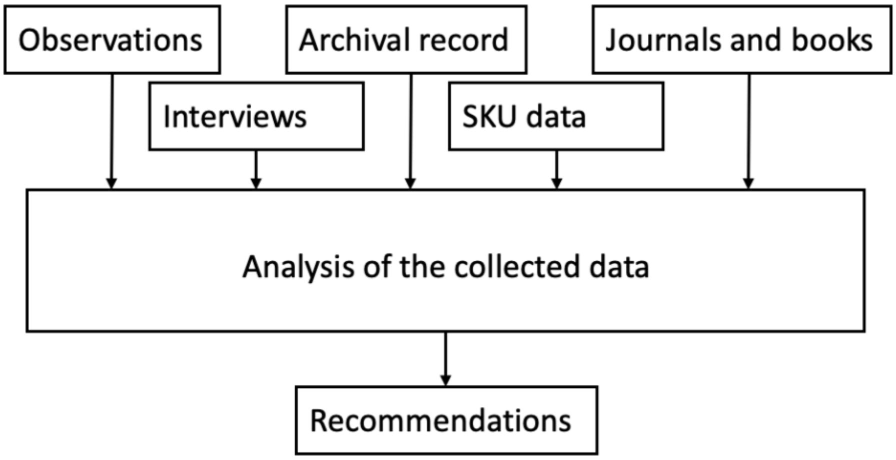

Figure 2.4 - An illustration of the data that were collected to result in recommendations

There were many different types of data that needed to be collected to make it possible to answer the objectives in the thesis. This made it important to get an overview of the data that were needed, when it should be collected, how and why it should be collected. This is presented in Table 2.1 below.

Table 2.1 - Which data to collect when, how, and why.

Data	**When**	**How**	**Why**
Company data (Financial, growth expectations, strategy)	From the start of the project	Company website, Annual report	To get an understanding of their strategy and expected growth to be able to plan with different horizons
SKU data	After the introduction, method, and theory chapter is performed	Extract through ERP	To analyse the current situation
How the process is currently working, and (first-hand) experienced issues. (From put-away to picking to production)	After the introduction, method, and theory chapter is performed	Observation of workers, interviews with the staff (both managers and factory workers)	To get an understanding of the current process, how to material flow looks like
What the goal of the change is	When the description is performed	Interviews of higher managers	To know which problems they have and why they would like to avoid them
Warehouse equipment solutions	During the empirics	Interviews and requests from different suppliers	To create a suitable solution

2.3.1 Primary and secondary data

The collected data in the research consisted of both primary and secondary data. They were both important but used in different amounts during different periods of the research. In the first phase, the define, prepare, and design of the research, almost all the information was collected through secondary sourcing. It consisted of journals and books from search sites including Web of Science and Lubsearch but also books from libraries. The purpose was to build up a bank of knowledge connected to warehousing which would facilitate the designing of a new warehouse and to know which data to collect. There was also primary data collected in the form of observations to get an overview of the current situation.

In the second phase, where the collection and analysis of the data was conducted, the data collected was mostly primary data. It was at this stage the picture of the real situation was created through interviews, data of the flow of coils, and observations in the factory. These interviews were also done to know the purpose of the new warehouse, the time horizon of the project, and what was useful with the current setup.

2.3.2 Quantitative data

Quantitative data is also commonly referred to as numerical data and should be measurable or countable. Examples of quantitative data are the number of people performing a task, or the dimensions of a physical object. Even though case studies often are associated with qualitative data, collecting quantitative data is also of importance (Voss et al., 2002). Case research provides the opportunity for the researcher to access information that otherwise may be difficult to retrieve due to e.g., privacy reasons (Yin, 2018). Quantitative data also provides strengths in terms of being more accurate and specific, as well as it covers a broader time span. One thing to consider though is that there is a risk towards both reporting bias by the author of the data, as well as bias when choosing which data that should be collected (Yin, 2018).

For this thesis, quantitative data was used to analyze the contextual situation of the coils to make decisions on a new warehouse design. By retrieving order data, it was possible to analyze in which quantities and how often each SKU was picked. This can be a baseline when deciding on where SKUs should be stored and which picking policy should be implemented (Govindaraj et al., 2000). Other examples include inventory data and calendar-clock profiling which will give insight on the seasonality and quantities stored in the warehouse and facilitate decisions of capacity requirements. Lastly, looking into the introduction of new SKUs is another valuable data set. This will affect the requirements of flexibility in the warehouse configuration to be able to handle the change in assortment (Bartholdi and Hackman, 2010). The quantitative data from the company was retrieved from information systems. Recommended data to collect by literature along with a short description can be seen in Table 2.2 below.

Table 2.2 - Recommended data to collect, based on (Bodner et al., 2002; Baker and Canessa, 2009; Govindaraj et al., 2000)

Type of data	Description
SKU data	Size, weight, storage mode of products
Inventory profile	What is in stock and at what time
Order profile	Order lines and number of SKUs per order
Seasonality	What was requested at what time and in what amounts
Current layout	Dimensions of potential existing building or site to be used

2.3.3 Qualitative data

Qualitative data is non-numerical and can be observed and recorded. It is typically collected through, inter alia, observations and interviews which are methods many associate with case studies (Voss et al., 2002). Since the purpose of this thesis was to design a new warehouse the goal of the collection of data was to get an overview of the situation, what employees think work and do not work with the current setup, and what the requirements were to make sure the new warehouse fulfills them both today and in the future.

Beginning with the observations conducted, the purpose was to get an understanding of how the coils have been stored and to see how the work is executed. The observations were also a complement to the interviews to both understand what they were talking about and to get information from multiple sources. The first observation consisted of a tour of the warehouse to see the setup of the warehouse and the area the new warehouse could be built on.

The purpose of the second observation was to see the work in action. This would provide information about the time it took to perform each pick and put-away, the equipment that was used, problems that existed with the current setup, and to understand the intensity of the flow of coils. It also raised questions that could be answered in interviews later on. Where the observations were done, when, and what the purposes were can be seen in Table 2.3.

Table 2.3 - The observations that was planned to be done and when

Observation of	**Date**	**Purpose**
The current warehouse	2020-12-15	To get a picture of how the situation is now, how is everything shipped and stored, and what steps are necessary
The working process	2021-02-25	To time activities, see the used equipment, and raise question for interviews
The storage locations	2021-03-16	To see if there were any other places the coils were stored at
The differences in storage	2021-03-19	To see how coils were stored with different width and get in contact with the computer system

When it comes to the interviews, they were supposed to provide information that could not be found in quantitative data, e.g., forecasts of the flow of coils and strategies, and to broaden the perspective through interviews with employees from different parts of the company. The broader perspective and to understand how a situation is from multiple perspectives is more likely to reflect the real situation than if the problem is only heard from one part, which is why interviewees were from many parts of the organization. This mix of persons that were interviewed, when, and the purpose can be seen in Table 2.4. The interview guide which was used can be seen in Appendix A.

The interviews with employees in the factory were supposed to provide information about problems they experience when executing their work, but also which solutions they might have to them. These interviews were also supposed to provide information of working procedures they might think are unnecessary to find areas of improvements. They were also supposed to answer how the flow of coils was and how efficient and effective they thought this process was.

While the employees at the factory provided information of how it was done, the interviews with office employees provided information of why, or how it was supposed to be according to the strategy if they did not match with each other. These interviews were also supposed to get a view of the problems with the current situation from another perspective which also was broader. They were supposed to provide information about the future plans of the organizational development which will facilitate the estimation of how long the new warehouse will function before any upgrades are needed.

Table 2.4 - The interviews that was planned to be held, with whom, and when

Interviewee	**Date**	**Purpose**
Warehouse manager: Kristian Jorlert	2021-03-19	To get another perspective of the working process
Truck driver: Tony Andersson	2021-02-25	Get to know the working processes
Warehouse team leader: Tobias Karlsson Simon Ahlqvist	2021-03-05 2021-03-19	To understand the current working process and which the needed steps are
Supply Chain Manager: Shrikrishna Tiwari	2021-03-16	To know the goal of the warehouse, timeframe, the strategy of the company, and more.
Informal shorter discussions with various employees, such as warehouse workers, factory manager, and production support	2021-02-25 → 2021-05-21	To understand how specific operations are performed and gather insights during the generation of the recommendations

2.4 Data analysis

After the first step of collecting the data was done it had to be analyzed, which was one of the most important steps of the research. Despite being the key to making the collected data valuable it is the least developed aspect of the case strategy (Yin, 2018). To get the best out of the collected data there needs to be a strategy in place on how to analyze it and what the result of the analysis should be. To have the strategy in place before the data is collected will make it easier to collect the right data to be able to analyze it effectively.

The analytical technique that was applicable to this research was pattern matching (Yin, 2018), also called casual network (Voss et al., 2002). The patterns in the data can both be found within the collected data itself and with the existing theory. Patterns which match the theory increase the validity of the result while nonmatching patterns indicate that a wider perspective is needed. The technique was used in two stages of the analysis. The first stage, see in Figure 2.5 as number 1, the pattern matching was used when the collected data first were analyzed. In this stage the pattern was between different sources, e.g., are there any recurring facts that are of greater importance. When it comes to the interviews the patterns were easy to identify, the persons interviewed brought up similar challenges and if only one person brought up a point it was assumed to be connected to their role. These patterns were also confirmed from the observations. In the second stage, see Figure 2.5 as number 2, where the described situation of Alfa Laval was matched with the best theoretical option. This pattern matching resulted in the identified suitable configurational elements which later was used to compose recommendations.

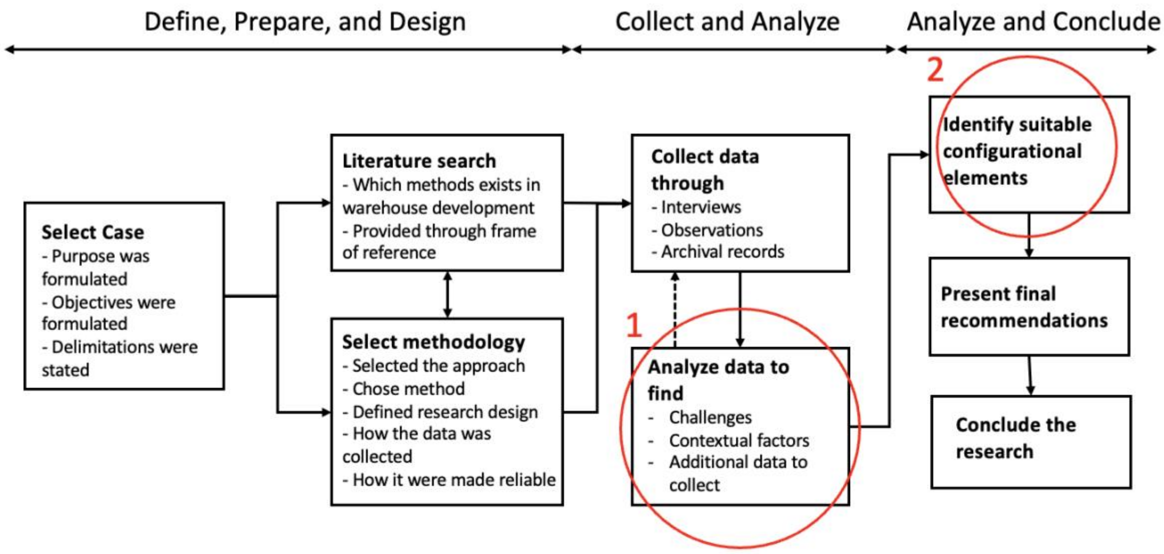

Figure 2.5 - Clarification of where the different analyzes are made.

Since there were two different types of data collected, qualitative and quantitative, the analysis differed between them. The first was the quantitative data regarding the coils and was supposed to answer research objectives two and three regarding the factors influencing the designing of a warehouse. The analysis of this data was to compare and connect it to the theoretical factors that were found in the frame of reference. Since this data consisted of straight numbers the analysis was more connected to finding patterns in it than the interpretation of what the numbers meant. Some patterns that were expected to be found were seasonal variability, the growth of the flow, the popularity of different coils, and the time it took from the arrival to the usage of the coil.

The second type of data was qualitative and consisted of observations and interviews. This data is also the most time consuming and consists of interpretation of what the response from an interview means (Basit, 2003). Information provided through interviews with different parts of the organization and from observations was analyzed to notice conflicting and matching statements. Both were searched for because the matching statements improved the reliability while conflicting statements could show the real picture. These patterns were not only searched for between the collected information from Alfa Laval but also compared to the existing theory.

Throughout the research and analysis of the data there were four principles from Yin (2018) that were followed. The first one is to include the important data that was collected in the analysis, even though it might include contrary information. These deviations should be presented but argued to not be included or that a reason behind them is presented. The reason to include the collected data is to show that it has been taken into account and that there has not been any cherry picking of the data to suit the conclusion. One example where this principle was applicable was the demand over a year. Even though the data showed a dip in demand, the dip was included but disregarded in the analysis due to other circumstances.

The second principle is to present other plausible solutions of the problem and not only the final recommendations. To bring up other plausible solutions together with the final recommendations and the advantages and disadvantages with all of them reinforces the argumentation to why the final recommendations are what they are. Some of the other plausible solutions might have flaws in loose ends, e.g., unclear information that might both be in favor or not, or that there are bigger tradeoffs than is necessary. If there are any solutions that might be better than the final recommendations but that the time remaining is not enough to investigate, they will be included in future analysis. This principle was used when different equipment was analyzed and put into the matrix of impact and effort of the solutions.

The third principle concerns the focus of what to analyze. The attention should be to analyze in favor of the main purpose of the report. An analysis which includes irrelevant analyzes gets more vulnerable to accusations that the sidetracks are there to divert the attention from contrary facts in the report. This principle was used by only analyzing the different options from the theory and to see which matched the situation at Alfa Laval the best. The fourth and final principle is to show that the subject is familiar to the authors through a good ground of theory in the report, which the report has.

The analysis of the data was also done in two steps to increase the chances of noticing different patterns. Since the research was done by two persons the analysis of the data could be done individually in the beginning. This lowered the possibility of affecting the other's way of thinking. This beginning may increase the risk of letting factors go unnoticed which is why the next step was to present the ideas to one another. The presentations both opened the eyes to the one presenting, because one has to understand before presenting, as well as giving ideas to the one listening. When all the ideas were on the table, they could both be combined to new ideas and improved through minor changes which improved the overall result. It was also in this step the week analyzes were removed from the process.

To be able to find connections and correlations between the different factors easier all the data was categorized. The categories had to be created with regard to one another to make sure they do not overlap (Basit, 2003; Voss et al., 2002).

2.5 Research quality

To create a good report, it is essential that the final recommendations can be credible, because without it the whole purpose of the report is eliminated. There are, according to Yin (2018), four different tests to work with to increase the credibility of the report. The different tests are to (i) construct validity through identification of the right operational measures for the situation of the study (ii) increase internal validity through a focus on establishing relationships which can lead to better information (iii) create external validity through demonstrating or arguing that the result can be generalized and (iv) increase the reliability through showing how the operation has been conducted to make sure it can be repeated with the same results.

Both validity and reliability are important to fulfill in a report because they serve two important purposes. Therefore, the difference between them is important to understand to know how the working method can improve either one of them. Figure 2.6 illustrates this difference through a dart board where the center is the subject of the research and each x marks which data is collected. The validity means that the data collected is about the subject the research is about. The reliability says that the data collected imply the same thing.

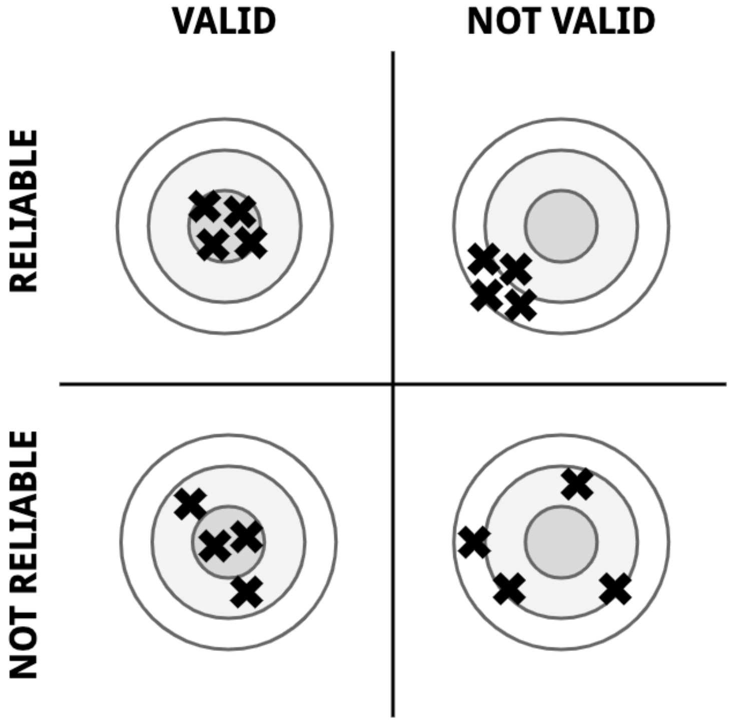

Figure 2.6 - An illustration of the difference between validity and reliability. (Le Cunff, n.d.)

To increase the credibility of this thesis the four tests from Yin have been done throughout the project. Table 2.5 states which tactic the case study should use to improve each one of the tests and also which phase of the project each tactic can be used in.

Table 2.5 - Methods to increase the reports validity and reliability, based on (Yin, 2018)

Tests	**Case study tactic**	**Phase which tactic is addressed**
Construct validity	1. Use multiple sources of evidence 2. Have key informants review draft case study report	1. Data collection 2. Composition
Internal validity	1. Do pattern matching 2. Do explanation building 3. Address rival explanations 4. Use logic models	1. Data analysis 2. Data analysis 3. Data analysis 4. Data analysis
External validity	1. Use theory in single-case studies 2. Use replication logic in multiple-case studies	1. Research design 2. Research design

Reliability	1. Use case study protocol 2. Develop case study database 3. Maintain a chain of evidence	1. Data collection 2. Data collection 3. Data collection

The construction of validity in this report has been done through a usage of multiple sources. As Table 2.5 states, the multiple sources are used in the data collection; it is also applicable to the theory collected throughout the whole report. The collection of data was done through multiple channels to get more perspectives on the situation. It was both through interviews and observations and the interviews were done with both employees at the factory handling the storage of coils and with the managers in the office responsible for the forecasts of the flow of goods. The second step in the construction of validity regards reviews from informants. This was done through continual checks with persons involved to make sure the given information is interpreted the right way. There were also continuous presentations along the way to give a picture of where the project was going to be able to find any problems before they grew too large.

The internal validity was increased in the analysis of the data collected. The analysis consisted of finding patterns both within the collected data and with the theory written in the frame of reference. The explanation building consists of putting the collected data in the context to understand why things are as they are. Since the research was not an explanatory research with the target to explain a certain situation the explanation building was not in the center of attention. Instead, it was used as a support to the pattern matching to avoid misinterpretation of the data because of situational factors. Results that state the opposite of the recommendation or the result of the report were also included in the analysis to show that some contrary facts exist. This information shows that there are multiple ways of solving any problem, but some factors are more important in other cases. These factors were used in an argument for why one solution was better than another because of the tradeoffs that exist between the different solutions. The final point in the case study tactic regarding the internal validity was that logic models were used when the design of a new warehouse was made. The models used are explained in the frame of reference and facilitate that all the aspects needed to be taken into consideration were included. Since this study was a single case study the external validity was done through inclusion of theory.

The final test from Yin (2018) concerns reliability and is connected to the collection of data. The same results should be achievable if the research were done again, and it is therefore important to document the process. During the collection of data through interviews and observations, protocols were used to make sure the information collected was correctly remembered when it was used later in the analysis. These protocols were also used to remember where interesting data were found when e.g., the archival data were collected. All the data that were collected were stored in a database to make it easier to find the right information when it was analyzed. The third tactic to get a reliable study is to maintain the chain of evidence. This was done through documentation of the decisions that were taken and on what grounds to make it possible to follow all the decisions.

3. FRAME OF REFERENCE

This chapter will cover important areas to consider within warehouse design to support the purpose of this thesis. The frame of reference is divided into four different parts: warehouse in general, warehouse configurations, contextual factors, and design frameworks. The first part serves as an introduction to warehouses, introducing the different types and purposes a warehouse may hold. Warehouse configuration takes a deeper view of warehouses by looking into its operations, and design and resources. This part discusses the physical layout and organization of resources to support the warehouse activities. The third part, contextual factors, is a literature review of existing identified factors that affect warehouse design. These will later be put into the context of Alfa Laval. Lastly, design frameworks that will aid the design process will be investigated. These frameworks will serve as a baseline for generating potential layouts. See Figure 3.1 for a visualization of this chapter.

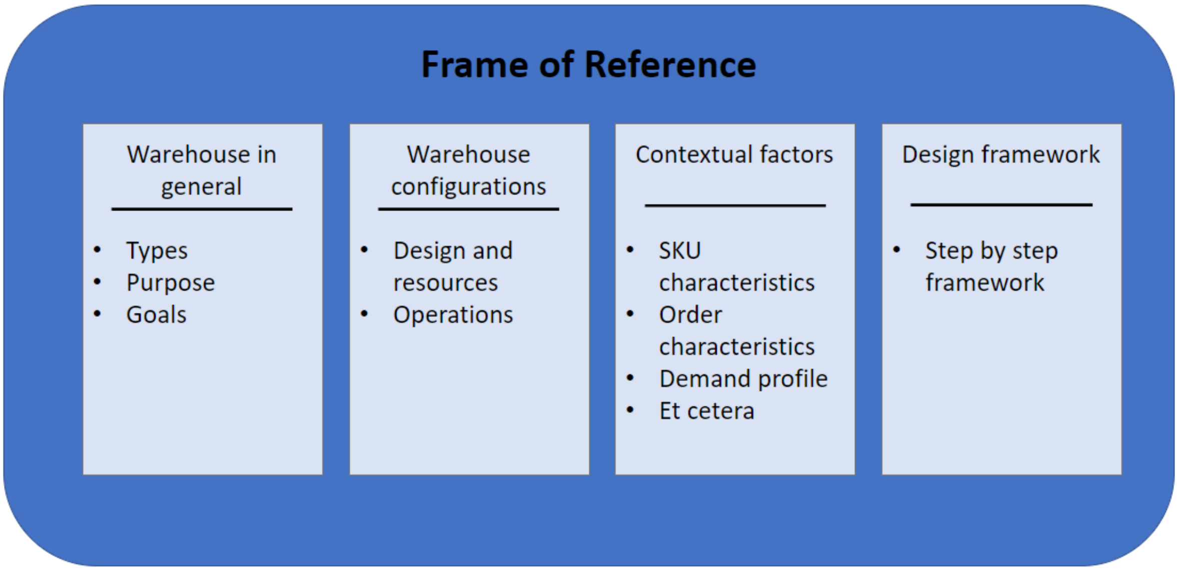

Figure 3.1 - Frame of reference chapter visualization

3.1 Warehouses in general

3.1.1 Types and purposes of warehouses

To be able to design a good layout it is important to understand the functions and characteristics of a warehouse. Rouwenhorst et al. (2000) distinguishes two different types: the distribution warehouse and the production warehouse. The distribution warehouse's major function is to store products for fulfillment of an often large number of customer orders. The assortment of different SKUs is often very high, and every customer order often consists of very few order lines, which lays the base for a complex and costly picking process. A main design criterion is therefore to maximize throughput. The function of a production warehouse is on the other hand to store goods associated with a manufacturing or assembly process, such as raw-materials or work-in-progress. These may be stored for longer time periods because of differences in such as procurement and production batches. A typical design criterion is therefore often the storage capacity.

Elaborating on the different types of warehouses, the warehouses can also be characterized on a more detailed level. Rouwenhorst et al. (2000) discussed three different groups: processes, resources, and organization. The processes include operations such as receiving, put-away, picking, and shipping (Bartholdi and Hackman, 2010). The resources refer to the equipment and manpower necessary to operate the warehouse. This may be equipment such as storage systems, various trucks, or information systems (Rouwenhorst et al., 2000). Lastly, organizations concern all planning and control procedures used to run the warehouse. This regard matters such as storage and picking policies (Rouwenhorst et al., 2000; Gu et al., 2007).

Another modified view of warehouse classification is presented by Jacyna et al. (2015), which Figure 3.2 visualizes. This view is based on the functions and tasks of the warehouse and includes aspects such as how material flows are directed and transformed, the level of value-adding activities, and storage period. The different sub-areas are type of business, level of distribution, production process level, storage type, inventory turnover, volumes of material flow, storage condition, and form of package. Each axis has representative values with the least complex value closest to the middle. This implies that more complex warehouses are present at the far ends, while lesser complex warehouses are centered in the middle of the spider chart.

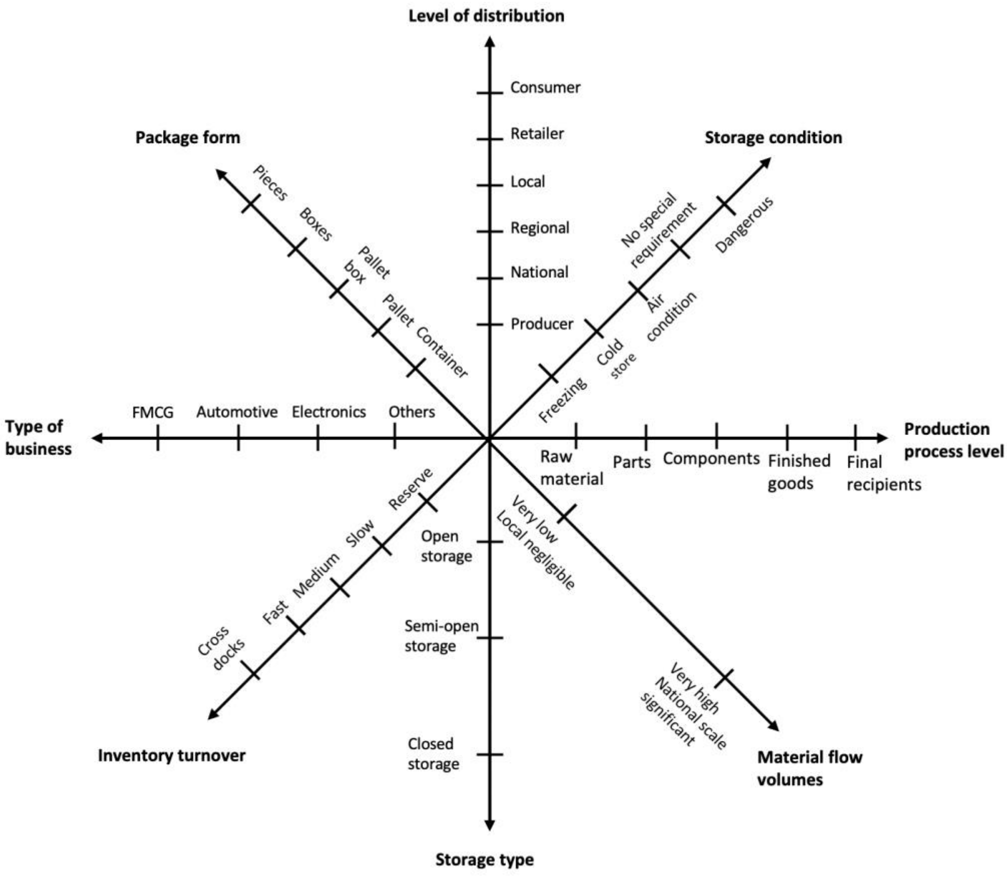

Figure 3.2 - Functional classification of warehouse facilities, based on (Jacyna et al., 2015; Vreriks, 2017)

3.1.2 Warehouse goals

How the warehouse should be designed is highly dependent on the goal with the warehouse. If the goal is to store as many items in the warehouse as possible the space utilization is the target, while if the flexibility and responsiveness of the flow is the goal the accessibility to all the SKUs is more important. These two examples are contrary, which many configurational elements are, and the warehouse cannot fulfill both of them at the same time and tradeoffs have to be made (Gu et al., 2010). But the goal can be to increase both of them as much as possible. This means that the goal of the warehouse has to be clear when it is designed to know which configurational goal to focus on. Kembro and Norrman (2019) brought up some of the configurational goals that warehouses could have, which are: reduced lead time, reduced material-handling costs, increased utilization of space, increased total throughput, improved safety, reduced travel time and distance, limited congestion, reduced administrative activities, and increased flexibility.

3.2 Warehouse design and resources

When describing a warehouse, it is important to understand the different available resources and how they are configured. These areas include the physical layout, equipment, automation solutions, information systems, and labor, and will be described in the following sub-chapters Both the impact and effort from changes in these areas is also important to take into consideration. The impact effort matrix (American Society of Quality, n.d.), seen in Figure 3.3, is one tool that facilitates the comparison between different changes.

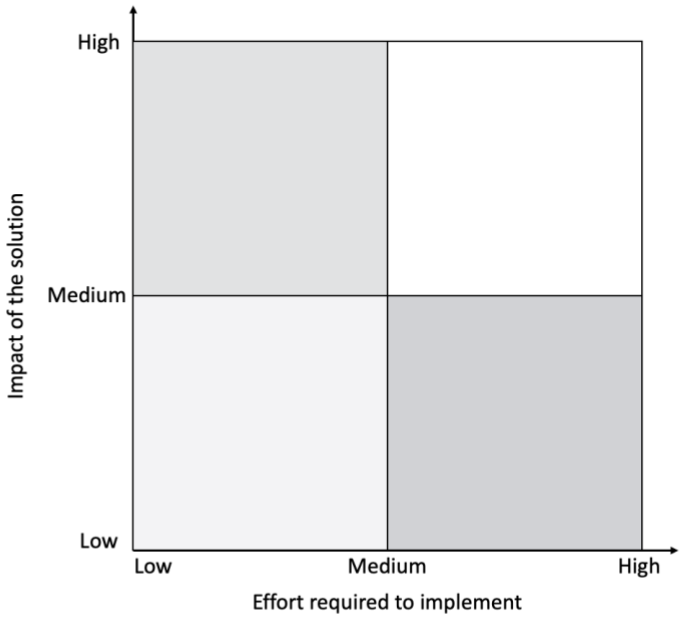

Figure 3.3 – Impact effort matrix, (American Society of Quality, n.d.)

3.2.1 Physical layout

The basic requirements for warehouse operations are to receive SKUs from suppliers, store the SKUs, retrieve them from their location, and ship the order to the customer. To meet these requirements resources such as space, labor, and equipment need to be allocated between warehouse functions to meet the capacity, throughput, and service levels (Gu et al., 2007). With the performance being largely determined in the planning phase, it is important to consider the design of the warehouse already from the start (Rouwenhorst et al., 2000). An important aspect of designing a warehouse is its layout. The design of the layout includes determining the number of aisles, their dimension and orientation, location of input and output, estimating space requirements, and many more (Hassan, 2002). This is a complex task because of the large number of possible decision combinations, making it difficult to find the optimal solution. Many of the decisions are also trade-offs that have to be considered (Rouwenhorst et al., 2000; Hassan, 2002). Bartholdi and Hackman (2010) divided the layout into three different areas to consider: space utilization, aisle configuration and location of receiving and shipping.

Space utilization is important to consider for cost-effective warehousing. Costs are often based on the square-meter of the warehouse, and by increasing the space utilization it is possible to decrease the cost per pallet location (Bartholdi and Hackman, 2010). Space requirements depend on various factors, such as aisles, inventory levels, and the size, type, and number of storage equipment (Hassan, 2002). One way to consider this is to increase the height of the storage. Installing pallet racks enables pallets to be stored on top of each other and increases the number of pallet positions per square-meter of floor space. There are different rack options available, and the decision should be based on a comparison of its gains versus the cost of installing the racks. Another way of affecting the space utilization is to adjust the lane depth. Aisles provide accessibility, not storage, and are therefore not directly revenue generating. By arranging locations in lanes these positions share the same aisle space and therefore also share the cost of aisles. Deeper lanes provide more pallet locations, but they also become less accessible for the pickers. It is therefore important to balance space utilization with material handling (Bartholdi and Hackman, 2010).

Aisle configuration is an important problem to consider because of its impact on space needs, operations, and material handling. Common decisions include the number and length of aisles, existence of cross aisles, and the number of storage blocks (de Koster et al., 2007). A large number of aisles consume space while a small number of them cause congestion. The decision of the configuration will therefore be a trade-off between large space and congestion (Hassan, 2002). The most common objective of all aisle configurations is to reduce the travelling distance within the warehouse (de Koster et al., 2007; Bartholdi and Hackman, 2010). If a picker is directed to another SKU location in the warehouse before returning to a checkpoint, such as the unloading dock, it may be beneficial in terms of reducing travelling distance to include cross-aisles, see the left configuration in Figure 3.4. Another idea, which is in contrast to the common parallel aisles aligned with the shipping and receiving docks, is to introduce angled cross-aisles. This is called a fishbone layout, see the right configuration in Figure 3.4, and could reduce the travel times by 20 % (Bartholdi and Hackman, 2010).

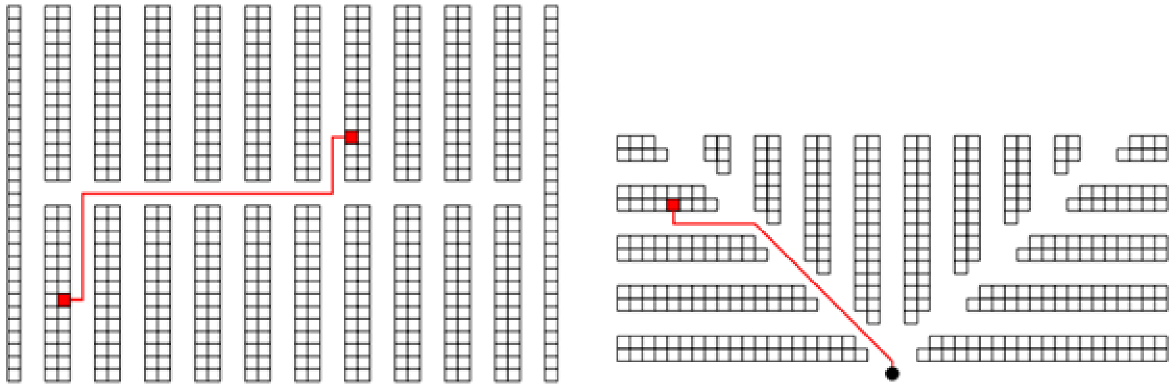

Figure 3.4 - Cross-aisle layout (left), Fishbone layout(right), (Bartholdi and Hackman, 2010)

The location of the receiving and shipping docks is another decision to consider when designing the layout. Two of the most common configurations in literature are flow-through and U-flow (Bartholdi and Hackman, 2010; Hassan, 2002; Huertas et al., 2007). With the flow-through configuration the receiving and shipping docks are located on opposite sides. Many positions are equally convenient, but very few are very convenient. This is appropriate for high volume warehouses and reduces congestion. The U-flow configuration has the docks located on the same side of the warehouse, making convenient locations even better while inconvenient locations are made even worse. This creates flexibility for the usage of the docks and their equipment and is suited for warehouses with few SKUs standing for a large portion of the picks (Huertas et al., 2007). The different layouts can be seen in Figure 3.5.

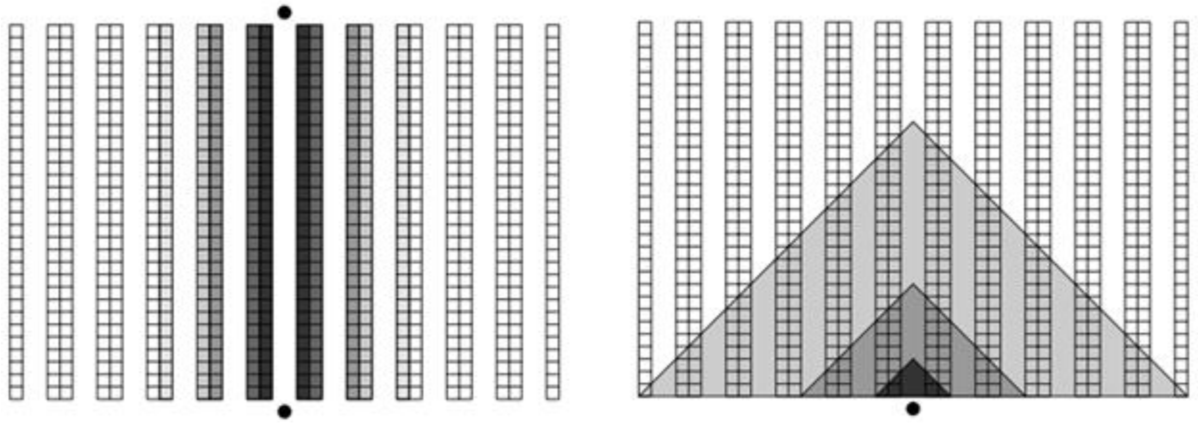

Figure 3.5 - Flow-through layout (left), U-flow layout (right). (Darker shading indicates more convenient locations), (Bartholdi and Hackman, 2010)

The physical layout decisions discussed above are summarized along with their advantage in Table 3.1 below.

Table 3.1 - Configuration decision of physical layout

Configuration area	**Sub-area**	**Reason**
Space utilization	Floor storage	Cheap
	Rack storage	Increase volume utilization
	Lane depth	Increase space utilization with deeper lanes
Receiving and shipping location	Flow-through	Many locations with good accessibility
	U-flow	Few locations with great accessibility
Aisle configuration	Many aisles	Less congestion
	Few aisles	Higher space utilization
	Cross aisles	Reduces travel distance for multiple picks

3.2.2 Equipment

To increase labor and space utilization a warehouse can choose between various storage and handling equipment. The storage equipment allows more SKUs to be presented on the pick-face, the front of the storage presented to the picker, and divides storage into subregions to enable denser packing. The handling equipment facilitates movement of SKUs from receiving to storage or from storage to shipping. (Bartholdi and Hackman, 2010). The name, description, as well as advantages and disadvantages of common storage equipment types are summarized in Table 3.2. Depending on which storage equipment that is used there is different handling equipment that can be selected. These are presented in Table 3.3 below.

Table 3.2 - Storage equipment types, based on (Bartholdi and Hackman, 2010)

Type	**Description**	**Advantage**	**Disadvantage**
Single-deep rack	Store's pallets one deep	Every pallet is independently accessible	Require more aisle space to access the pallets
Double-deep rack	Store pallets two deep	Every lane is individually accessible, requires fewer aisles	Risk's double-handling because of LIFO, requires a special truck to reach
Push-back rack	An extensive of double-deep racks and works like a drawer	Pallet positions are more accessible	Risk of double handling because of LIFO
Drive-in rack	Allows a lift truck to drive into the rack to access the SKUs. Retrieval and put-away is done from the same side	Good for space utilization	Risk of double handling because of LIFO. Slower to retrieve and put-away
Drive-through rack	Allows a lift truck to drive into the rack to access the SKUs. Retrieval and put-away is done from opposite sides	Good for space utilization. Enables FIFO operations, put-away and retrieving to can be performed individually	Slower to retrieve and put-away

Flow through rack	A deep-lane rack with an angle which moves the coils to one end of the rack	Good for space utilization. Enables FIFO operations, put-away and retrieving to can be performed individually	Less suitable for an assortment with many articles with few of each

Table 3.3 - Handling equipment types, based on (Bartholdi and Hackman, 2010; Rushton et al., 2014)

Type	**Description**
Counterbalance truck	Standard truck version
Reach truck	Enables forks to extend to reach pallets further in
Turret truck	Enables the truck to turn 90 degrees in any direction
Overhead travelling cranes	Normally consists of a lifting device attached to a beam that travel on two rails fixed high on poles

3.2.3 Automation solutions

Warehouse operations require large space for facilities and tend to be labor intensive. Storing SKUs in racks and moving them through aisles requires large facilities, and order picking is a repetitive activity of poor ergonomics (Azadeh et al., 2019). With both land and labor being limited and expensive, many firms have turned towards automation (Baker and Halim, 2007). Warehouse automation can serve as a substitute for labor. One example of this is the Automated Storage and Retrieval System (AS/RS) which consists of an automated device within each aisle that can move both vertically and horizontally to store and retrieve products.

Decisions regarding warehouse automation should be considered carefully and are not suited for all circumstances. Automation is good at performing the specific task it was designed for and if able to run constantly it can prove to be a good investment decision (Bartholdi and Hackman, 2010). It can also help accommodate growth by making better use of the available resources, where e.g., physical expansion or acquiring more labor is not an option (Baker and Halim, 2007). However, automated solutions have complex and long implementation processes and are very inflexible to meet changing market requirements such as new product requirements (Bartholdi and Hackman, 2010; Baker and Halim, 2007). To facilitate this decision, Naish and Baker (2004) have created an assessment tool which can be seen in Figure 3.6. The level of automation is there based on the through-put and number of SKUs in the warehouse.

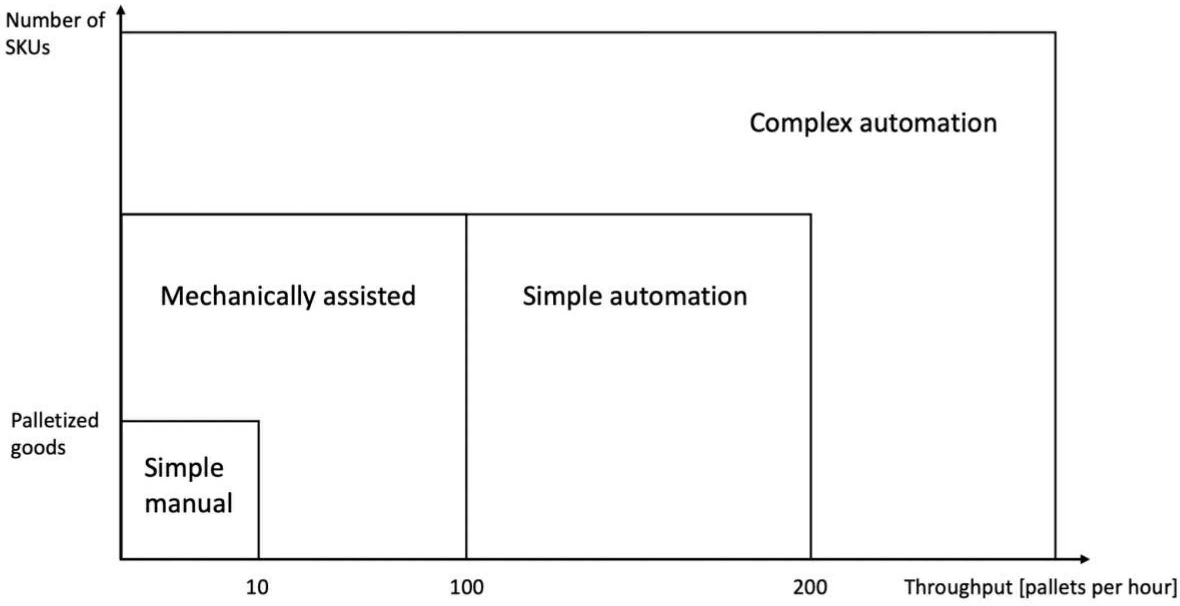

Figure 3.6 - Automation assessment tool, (Naish and Baker, 2004)

3.2.4 Information systems

Information systems play an important role in handling complex processes, such as warehouses, and selecting the correct system that is suitable is not a trivial task. This is because of the many different software solutions available on the market (Faber et al., 2013). These softwares can either be general and be connected to many different departments of the company or specialized in certain functions like warehousing. The broader solutions often support various processes in the company, such as an Enterprise Resource Planning (ERP) system. While these offer wide functionalities it is difficult to configure them for specific situations. The specialized solutions on the other hand support fewer processes but with more depth, e.g., a WMS (Faber et al., 2013).

Having the correct information about products, resources, and processes at the right time is crucial for achieving high performance in a modern warehouse. A WMS makes it possible to efficiently manage both inbound and outbound processes by controlling the physical and informative flows within a warehouse (Baruffaldi et al., 2019; Faber, 2002). A WMS can gather, store, and provide information regarding processes, products, and resources to other modules of the company's ERP (Baruffaldi et al., 2019). Since a warehouse can be seen as a node in the flow of products, it is of importance that the WMS communicates with other administrative functions such as procurement, production control, and transportation. It is becoming more and more common that these are integrated into the ERP. In contrast to the ERP, which has a planning horizon of several weeks and covers functions located all over the company, a WMS is limited to the warehouse function and has short-term planning, shop-floor control, and warehouse activities (Faber, 2002). In addition to having to communicate with other administrative functions, a WMS also has to communicate with technical functions such as Radio Frequency Identification and AS/RS control systems to control material handling and movement within the warehouse (Rushton et al., 2014).

A WMS can have different levels of complexity and are categorized as basic or advanced systems depending on which functions are included. The more basic functions included in a WMS are connected to processes such as receiving, put-away, and picking (Bartholdi and

Hackman, 2010). This can refer to tools that support stock and location control with the help of e.g., scanning systems. The system could also generate, and display, storage and picking instructions. In general, the basic WMS is simple and focuses on throughput (Faber, 2002). The more advanced WMS on the other hand can offer tools that enable optimizing the warehouse. This regards complex storage allocation strategies, optimizing the picking route to minimize travelling distance, as well as supporting value-adding activities (Bartholdi and Hackman, 2010; Faber, 2002). To get a visualization of which functionalities the different systems support, a figure constructed by Nettsträter (2015) is presented in Figure 3.7 below.

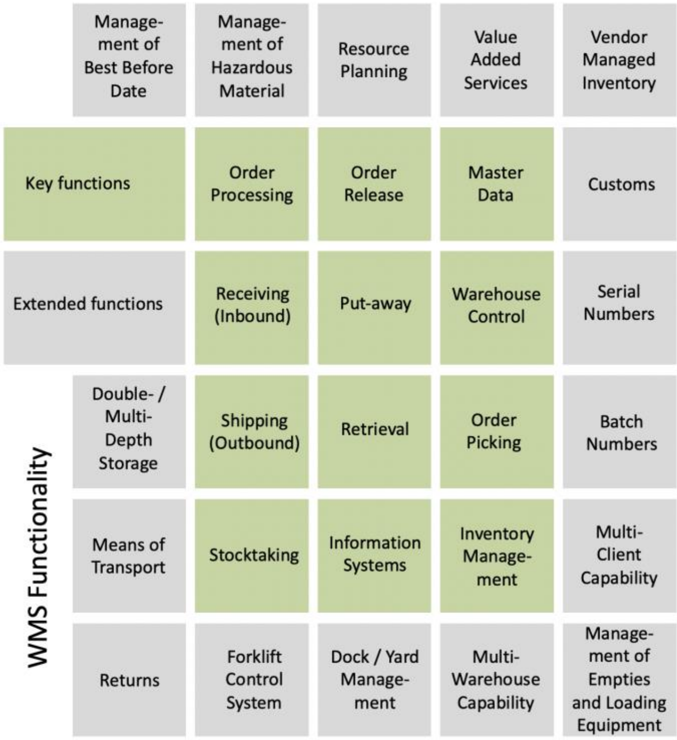

Figure 3.7 - Visualization of different WMS functions, (Nettsträter ,2015)

There are many benefits that can be gained by implementing a WMS. Harb et al. (2016) investigated a private company and found that locations became clear and well defined, in comparison to the previous crowded warehouse. There was also a much higher accuracy in stock level reporting. Furthermore, a WMS can help solve problems related to manual tasks and errors, and incorrect storage locations (Anđelković and Radosavljević, 2018). It also presents opportunities to adapt the operations to your context by introducing storage policies based on algorithms of e.g., weight, shape, or First In First Out (FIFO) (Wang, 2010). Companies that have chosen to not implement a WMS in their warehouse are at a competitive disadvantage and are less prepared for changes in customer demand (Faber, 2002; Baruffaldi, 2019). It is important to consider that implementing the wrong WMS may also lead to a competitive or cost disadvantage. It is therefore needed to carefully consider which functions should be included (Faber, 2002).

3.2.5 Labor and activities

Warehouses require labor to operate, and it is important to manage this resource efficiently, especially since it in many countries is an expensive resource. Activities downstream are often more labor-intensive because of the involvement of smaller handling units, such as picking of cases or single packages. A warehouse typically bills its customers for a fixed handling cost but pays its forklift drivers per hour. It should therefore be a goal to maximize the number of handles per hour a worker performs. (Bartholdi and Hackman, 2010) A way to improve warehouse performance is through manpower planning. Strategies of this can be to employ temporary workers to cope with variations of demand and supply in labor because of e.g., seasonality. Another way to cope with this is to create more flexible contracts for fixed employees, so that the number of work hours per year is distributed in line with the demand of labor (De Leeuw and Wiers, 2015). De Leeuw and Wiers (2015) also mentions job rotation, where workers are able to switch between multiple tasks in the warehouse, and workload balancing, where orders are postponed from busy days to quiet days to even out the workload and reduce cost for overtime and temporary staff. The different methods to cope with demand variations is summarized in Table 3.4 below.

Table 3.4 - Methods of handling demand variations

Area	**Method**	**Description**
Labor management	Temporary workers	Flexibility on number of full-time employees
	Flexible contracts	Flexibility on working hours
	Job rotation	Flexibility on number of employees at different functions inhouse
	Work-load balancing	Flexibility by postponing orders to get an even flow

3.3 Warehouse operations

Every warehouse should be designed according to the requirements set by its supply chain and may serve different purposes. Despite that, many warehouses have certain operations in common. Literature has agreed on a similar view of these common processes and describes them as receiving a shipment, storing the products, picking the demanded products, and shipping them to the customer (Bartholdi and Hackman, 2010; Rouwenhorst et al., 2000; Gu et al., 2007). A graphical view of these operations and their order is seen in Figure 3.8 below.

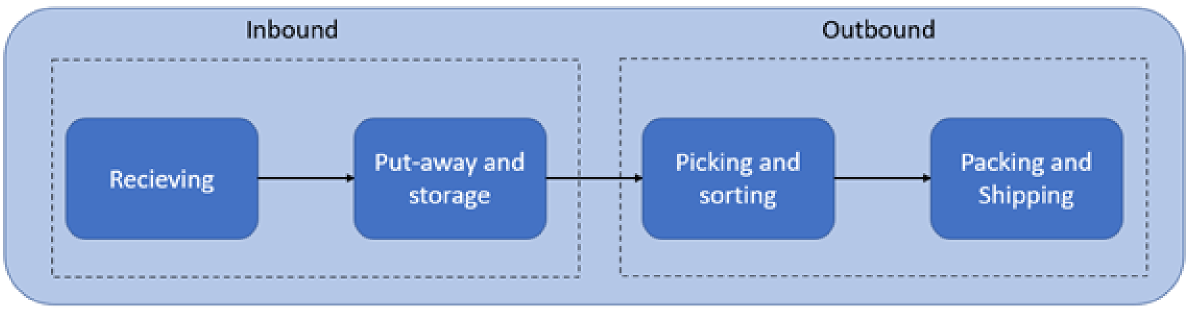

Figure 3.8 - Warehouse operations, adapted from de Koster et al. (2007)

3.3.1 Receiving

The warehouse operations begin with the goods arriving in a loading unit at a scheduled slot (Gu et al., 2007). Once the goods have arrived, they are unloaded and prepared for put-away. Activities performed include shipment confirmation, e.g., scanning, so that ownership is transferred, and inventory levels updated. Products are also inspected for deviations so that claims can be charged for incorrect or damaged units (Bartholdi and Hackman 2010; Rushton et al., 2014). Incorrect products will have an impact on the put-away, storage, picking and shipping by risking stocking the bay area. The incoming goods often arrive in pallet-loads and are in certain cases repacked into different storage units before they are transported to the next process (Bartholdi and Hackman, 2010; Rouwenhorst et al., 2000). To support these activities there is a need for sufficient information systems and material handling units.

3.3.2 Put-away and Storage

The designated storage location largely determines the speed and cost of retrieving the SKUs and it is therefore important to consider when putting away the received goods (Bartholdi and Hackman, 2010). When the goods are taken from the receiving area and placed at the storage location, they are also scanned to update the inventory positions in the system. Information such as weight, dimensions, and positions available facilitates the put-away process. Because of the large distance travelled from the docks to the storage locations the costs can account for up to 15 % of the total warehouse expenses (Bartholdi and Hackman, 2010).

The assigned storage locations depend on the warehouse storage policy (Gu et al., 2007). Bartholdi and Hackman (2010) discuss two main strategies for storing a product, dedicated and shared. With dedicated storage each storage location is assigned a specific SKU. This results in workers learning the layout and enabling popular products to be placed in convenient locations. On the downside, using dedicated storage lowers the space utilization of the warehouse. When SKUs are out of stock their dedicated locations are empty and no other SKUs can be placed at their location. This strategy is on average resulting in a utilization of 50 % (Bartholdi and Hackman, 2010). To improve the space utilization shared storage is suggested. This strategy is based on a SKU being assigned more than one location. If a SKU is out of stock, it is then possible to reassign the location to another SKU instead of waiting for the original product to be replenished. The problem with shared storage is that it makes the put-away process more time consuming because of products having to be taken to several locations. It is also possible to divide the warehouse into a bulk area used for replenishment and a picking area where lesser unit loads are picked from, also called forward-reserve strategy (Gu et al., 2007, Rouwenhorst et al., 2000). The idea is to facilitate the picking of fast-moving products. This reduces the picking costs but increases the material handling costs by having to restock the forward area from the reserve area (Gu et al., 2007). The general idea of this strategy can be seen in Figure 3.9 below.

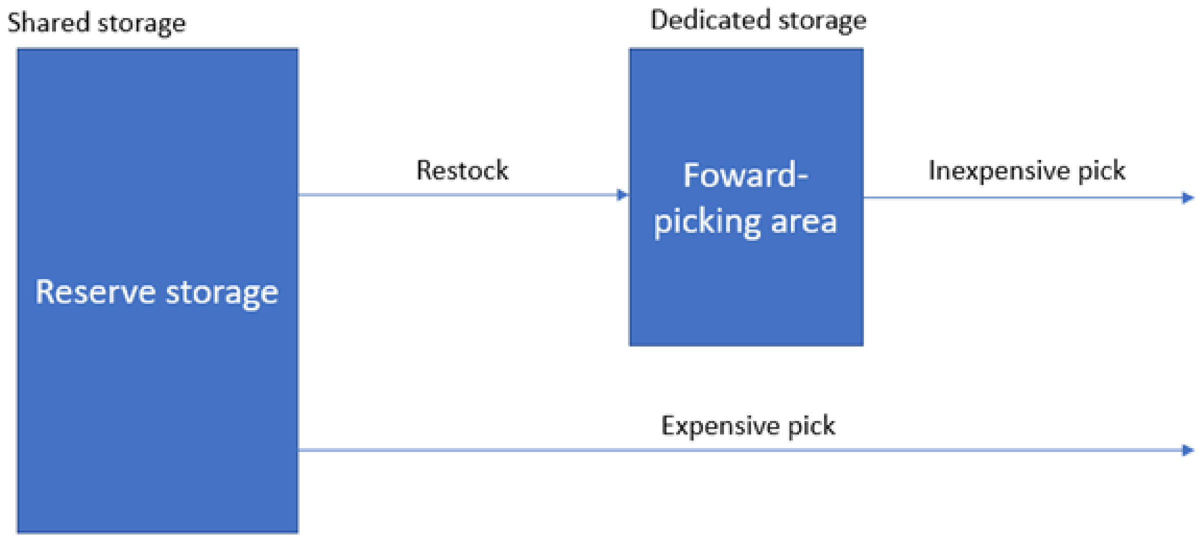

Figure 3.9 - Forward-picking strategy, adapted from Bartholdi and Hackman (2010)

In addition to the shared and dedicated storage assignments policies there are also class-based storage and family grouping. A class-based policy is a combination of the shared and dedicated storage and is suitable for warehouses with SKUs that have large differences in popularity. The SKUs are divided into classes, commonly in up to four groups, based on their pick frequency. The different classes are then assigned to a dedicated area within the warehouse where within the area there is shared storage. The final storage policy, family grouping, takes into account which SKUs that are often requested together, such as batteries and flashlights, and stores them next to each other to minimize travelling. Family grouping can also be complemented with the other policies mentioned above (Gu et al., 2007; Rouwenhorst et al., 2000).

3.3.3 Picking and Sorting

Picking is the most labor-intensive activity within a warehouse and stands for about 55 % of its total operating costs (Bartholdi and Hackman, 2010; de Koster et al. 2007; Davarzani and Norrman, 2015). Therefore, it is important to consider how the picking is done in the warehouse. The picking process is initiated with the receival of a customer order which states which SKU and in what quantity it is requested (Rushton et al., 2014). This order is then transformed into a pick list, where every pick-line corresponds to which location and in what quantity it should be picked. If the warehouse uses information systems these can reorganize the picking list for greater efficiency (Bartholdi and Hackman, 2010). A general decision to take is if orders should be picked in parallel or in serial. With parallel picking orders are picked in parallel by multiple workers at a time while serial picking implies that the order is picked by one worker at a time. The trade-off of this decision is that picking in parallel is faster but requires the items to be consolidated and sorted at a later stage (Bartholdi and Hackman, 2010). Another decision to take is regarding which picking policy should be employed. Literature has discussed different picking policies such as single-order picking, one order is picked per tour, and batch picking, a set of orders are grouped and picked by a single tour, and they all consist of some or all the following basic steps: batching, routing and sequencing, and sorting (Gu et al., 2007; Davarzani and Norrman, 2015).

Batching is a picking policy where different customer orders are grouped into batches so that they can be picked simultaneously during a single tour. The accumulated picked articles are then consolidated and sorted during a set time window before the next batch is performed (Gu et al., 2007). This is a preferred method when orders are small and it is contrary to a single order picking policy where one order is picked per picking tour (de Koster et al., 2007). Batching requires additional activities such as sorting to be performed. This can be done either while picking, or when the batch is complete and consolidated (Gu et al., 2007).

Routing and sequencing deals with sorting the items on the pick list to ensure an efficient route as possible through the warehouse (de Koster et al., 2007). With travelling accounting for over half of the total picking costs, the objective is typically to minimize the total handling costs (Bartholdi and Hackman, 2010; Gu et al., 2007). The optimal picking route may be illogical for pickers, require advanced software support, and does not take aisle congestion into account. Therefore, a common solution in practice is to apply heuristic methods (de Koster et al, 2007). Petersen (1997) discussed five different heuristic routing policies which can be seen in Figure 3.10.

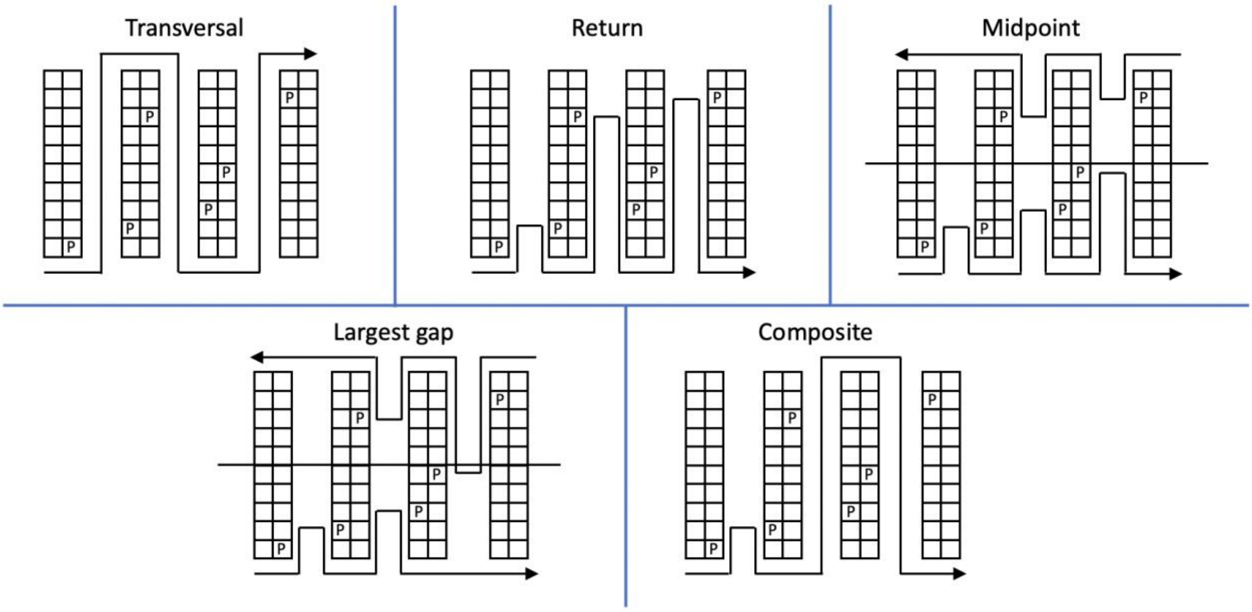

Figure 3.10 - Routing methods, adapted from Petersen (1997)

The most basic heuristic for routing is the Transversal. With this method the picker enters an aisle if it contains a pick and travels through the aisle. Another version of this is the Return strategy, with the only difference of the picker entering and leaving an aisle from the same end. The Midpoint strategy divides the warehouse into two sections. The picker can then only access picks as far as the mid-point before returning. The Largest gap policy is a modified version of the Midpoint strategy. The difference is that the picker enters an aisle as far as the largest gap within an aisle, instead of the midpoint. The gap represents the distance between two adjacent picks. The last method described is the Composite policy. This is a combination of the transversal and return policy.

3.3.4 Packing and Shipping

After the orders have been retrieved and sorted, they are packed and shipped. Activities that can be performed include kitting, labeling, or shrink-wrapping smaller units to a pallet (Rushton et al., 2014). In this phase it is also important to consider scheduling of trucks at the shipping docks (Gu et al., 2007). The goods are also likely to be scanned during the loading process to ensure that the inventory is updated, and ownership transferred (Bartholdi and Hackman, 2010).

3.3.5 Operational configuration options

The subsections above have discussed the different setups of the warehouse operations. The options available as well as their suitability is summarized in Table 3.5 below.

Table 3.5 - Configurational decisions within warehouse operations

Configuration area	**Sub-area**	**Reason**
Storage policy	Shared storage	Places SKUs randomly and enables higher space utilization, but with the downside of greater travelling distances
	Dedicated	Allocates locations for special SKUs of e.g., heavy weights, but with the downside of lower space utilization
	Class based	Suitable for large differences in SKU popularity.
	Family grouping	Enables similar SKUs that are requested together to be stored next to each other.
	Forward picking area	Many popular, less than pallet-loads, orders
Picking strategy	Parallel	Multiple workers per order (requires sorting)
	Serial	One worker per order (requires no sorting)
Picking policy	Single order	Few orders with many lines each
	Batch	Many small orders with few lines
	Routing	Minimize traveling distance per pick

3.4 Warehouse contextual factors

As seen in this chapter, designing a warehouse involves many interrelated decisions of varying complexity and level of detail. One must understand the warehouse type, whether it serves as a buffering point to accommodate for the difference in production and procurement batches or if its function is to meet an uncertain demand of customer orders, i.e., production or distribution warehouse. Both of these classifications will have a direct impact on the design, resources, and operations of the warehouse. Further on, resources and how they are designed, e.g., type and orientation of storage equipment, need to be considered. It is also of importance to decide how the warehouse should operate in terms of picking and storage strategies. These are only a few of a large number of decisions that need to be considered when designing a warehouse, all of which have an impact on the performance.

All of the decisions above relate to the context in which the warehouse, and its supply chain, operates in. It is therefore important to understand how contextual factors affect the warehouse configuration. Tailoring the warehouse configuration with its contextual factors has seen increasing popularity in recent literature (Kembro and Norrman, 2020). Some examples of contextual factors discussed are product characteristics, supply chain design, financial, and operational factors (Da Cunha Reis et al., 2017; Bartholdi and Hackman, 2010). Faber et al. (2013) discusses two categories: task complexity and market dynamics. Task complexity includes number of SKUs, process diversity, and number of order lines while market dynamics refers to demand unpredictability and assortment changes. Onstein et al. (2018) divides the contextual factors into seven groups, demand level factors, service level factors, product characteristics, logistics costs factors, labor and land availability, accessibility, and contextual factors, where the last refers to local regulations and laws.

As stated above, there are different contextual factors and ways to categorize them, but common to all authors are that the contextual factors all have an impact on the warehouse configuration and are all dependent on their context. An overview of different examples of contextual factors can be seen in Table 3.6. Each contextual factor can have a different impact in different contexts, and it is therefore important to see if the factor is one of the main factors in a certain context or not.

Table 3.6 - Examples of contextual factors, based on (Onstein et al., 2018; Da Cunha Reis et al., 2017; Kembro and Norrman, 2020; Faber et al., 2013)

Contextual factor	**Description**
Product characteristics	Refers to the number of SKUs, their size, and variety. It has an impact on the space and type of equipment needed.
Order characteristics	Refers to the number of orders, order-lines per order, and SKUs per order. This will impact the picking process.
Customer characteristics	Refers to the number and type of customers, as well as their preferences. This will have an impact on assortment if value adding services are necessary.
Demand profile	Refers to seasonality of demand and how often SKUs are picked. This will influence storage strategies and labor profiles.
Volume profile	Refers to the throughput of the warehouse.

Regional situation	Refers to land and labor costs in the region. This will affect automation level and footprint decisions.
Physical layout	Refers to the shape and building the warehouse is within. It influences the dimensions the warehouse can have.
Information systems	Refers to the capabilities the current information system has and what it can be complemented with.

Both how the products are handled and how they are stored is highly dependent on the characteristics of the product (Rouwenhorst et al., 2000). For instance, the size of the SKU can affect which storage equipment is usable. This could be drawn into the extreme where large SKUs, weighing over 20 tons, only can use special racks or that they need to be stored on the ground because of their characteristics. In this case the movement of one SKU requires handling equipment that can withstand the weight. There is also the factor of environmental requirements such as the temperature or the humidity. These can be seen in the pharmaceutical industry (Maltesson and Sandberg, 2020) where there is no tolerance in broken cold chains. Another example of where the product characteristics affect the storage and handling is if the measures of the products have a wide range. This could mean that the shelfs in racks need to have different heights that suit the different SKUs and at the same time optimize the space utilization.

The customers can, as well as the product characteristics, affect the possibilities on how to store the SKUs in the warehouse but they can also affect which systems that are needed. In this case, the customers could demand a traceability of the product all the way in the supply chain which means that there needs to be a system in place to handle this requirement, like a WMS (Baruffaldi, 2019). How the SKUs are stored is affected by the customer through their unpredictable demand. The solution could be to make the storage more flexible with shorter picking times to be more responsive and through that fulfill their requirements (Kembro and Norrman, 2020).

3.5 Warehouse design framework

As discussed in this chapter, designing a warehouse involves a large number of decisions, which often are of conflicting nature, and many decisions require trade-offs to be considered (Rouwenhorst et al., 2000). It is difficult to determine a strict border between these decisions because of the interconnection and relationship between them (Gu et al., 2010; Baker and Canessa, 2009). To avoid sub-optimization, it is important that these relationships are considered (Rouwenhorst et al., 2000). The process typically follows certain phases, from functional description, through technical specification, to equipment selection and determination of layout, and in every stage, requirements have to be met (Rouwenhorst et al., 2000). This makes warehouse design a highly complex task, which is emphasized by the large number of possible designs (Hassan, 2002). Baker and Canessa (2009) states that there appears to be no simple optimization solution for the design process where inputs are transferred to an optimal design.

To facilitate the designing of a warehouse, literature has presented several different frameworks. Rouwenhorst et al. (2000) divided the different decisions, and previously mentioned stages, into strategic, tactical, and operational levels. It is then argued for a top-down approach to consider these levels in sequence. Other authors have presented similar models but organize the decision into a series of steps to be followed. Hassan (2002) created a 14-step model aimed to facilitate the process by addressing the overall layout in sequential order. Baker and Canessa (2009) reviewed a number of existing step-by-step models in the literature and created a common model with aiding tools. Rushton et al. (2014) also described a framework consisting of 13 steps. The developed steps can be seen in Table 3.7 below. These will be used to facilitate the generation of different layouts to Alfa Laval.

Table 3.7 - Step-by-step models for warehouse design

	Baker and Canessa (2009)	Hassan (2002)	Rushton et al., (2014)
1	Define system requirement	Specify the type and purpose of the warehouse	Define business requirements and design constraints
2	Define and obtain data	Forecasting and analysis of expected demand	Define and obtain data
3	Analyze data	Establishing operating policies	Formulate a planning base
4	Establish unit loads to be used	Determining inventory levels	Define the operational principles
5	Determine operating procedures and methods	Class formation	Evaluate equipment types
6	Consider possible equipment types and characteristics	Departmentalization and the general layout	Prepare internal and external layouts
7	Calculate equipment capacities and quantities	Storage partition	Draw up high-level procedures and information system requirements
8	Define services and ancillary operations	Design of material handling, storage, and sortation systems	Evaluate design flexibility
9	Prepare possible layouts	Design of aisles	Calculate equipment quantities
10	Evaluate and assess	Determining space requirements	Calculate staffing levels
11	Identify the preferred design	Determining the number and locations of input/output points	Calculate capital and operating costs

12		Determining the number and location of docks	Evaluate the design against business requirements and design constraints
13		Arrangement of storage	Finalize the preferred design
14		Zone formation	

By looking into the different step-by-step models proposed by literature it is possible to identify similarities between the models. The common first two steps include defining the requirements of the warehouse and obtaining data. This relates to the role of the warehouse, e.g., if it serves as a cross-docking facility or decoupling point, and specified activities such as production postponement and value-added services. This will have an effect on both the throughput level and space utilization. Defining this early is important since they will all have an effect on subsequent steps in the design. The data that should be obtained can be categorized in different groups. Product and order characteristics, receival and dispatch patterns, operations, and cost data include some of the information required for the design.

The next common steps relate to defining the functional and technical requirements of the warehouse. This includes determining the inventory levels the warehouse should be designed for and what kind of unit-loads that should be handled. With the role being determined in the former steps, and therefore the basic operation of the warehouse, it is now possible to determine the operations in a more detailed level. This will include the sequence in which activities should be performed and the type of policies used. The technical side of this part will include the equipment that should be used, e.g., what type of racks and forklifts, as well as their quantities.

Lastly, the common final steps include generating different layouts and evaluating their performance. The preparement of layout suggestions includes decisions on the type of flow, e.g., U-flow vs flow-through, and the size and dimensions of departments, as well as determining zones and aisle configuration. By evaluating the suggested layouts, it is possible to select the preferred design. It should be noted that despite the structure of the frameworks in Table 3.7, warehouse design tends to be an iterative process rather than a fixed set of sequential steps. Therefore, the order of steps varies between authors.

3.6 Analytical Structure and Framework

The frame of reference will be used to analyze the collected data to be able to generate two recommendations of how the new warehouse should be designed. The structure of how the objective in the report relates to the purpose can be seen in Figure 3.11 and it also shows in which chapter each of the areas are brought up. The first objective will be answered by looking into the current situation of the operations, design and resources of the case company. This will also enable the identification of the current challenges which is part of the second objective. These challenges are then analyzed together with the identified contextual factors. The focus will be to investigate how these challenges and factors influence the warehouse configuration. This will regard the operations, such as put-away, storage, and picking, as well as design and resources, such as layout, equipment, and information systems. The knowledge gained from these areas will then be used, together with the warehouse goals and theory foundation, to solve the challenges while keeping the contextual factors in mind. This will fulfill the purpose of the thesis by generating two new designs of the coil warehouse.

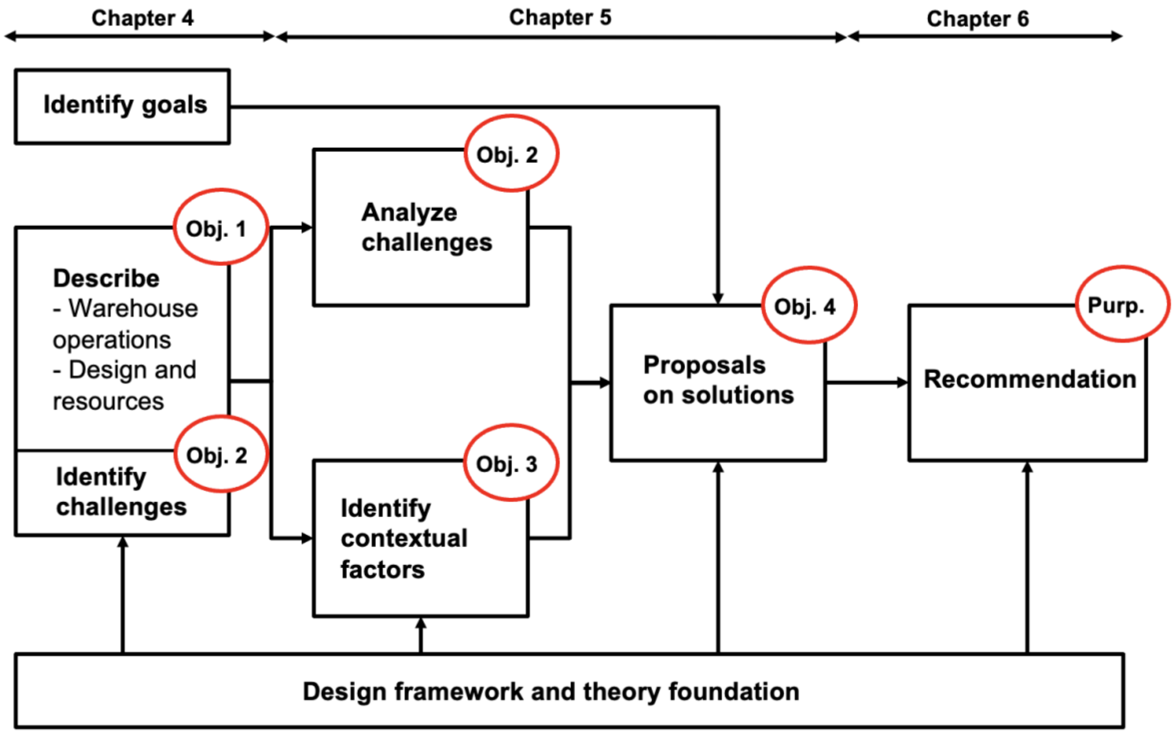

Figure 3.11 - Analytical structure

The analytical framework in Figure 3.12 will be used to narrow down the research to the situation of Alfa Laval. This will be done with the guidance of the tools presented in this chapter. These include the suitable level of automation depending on the throughput and number of SKUs, suitable functions for a WMS, and a classification of the complexity of the warehouse. It also includes several tables, with different decisions on each configural element, that are used to analyze the empirics with the goals, description, challenges, and contextual factors in mind. The first decision table is regarding the physical layout which includes the aisle configuration and the location of receiving and shipping. As an example, if the collected data shows that there are high volume flows with risk of congestion, the table tool suggests that the configurational elements within this area should be flow-through configuration with many aisles. Together with the other table tools this will result in several different individual configurational elements. In the recommendation chapter these elements will be merged into two holistic warehouse configurations that addresses the goals and identified challenges while taking the contextual factors into account. The generation process will be supported by the warehouse design frameworks presented in chapter 3.5.

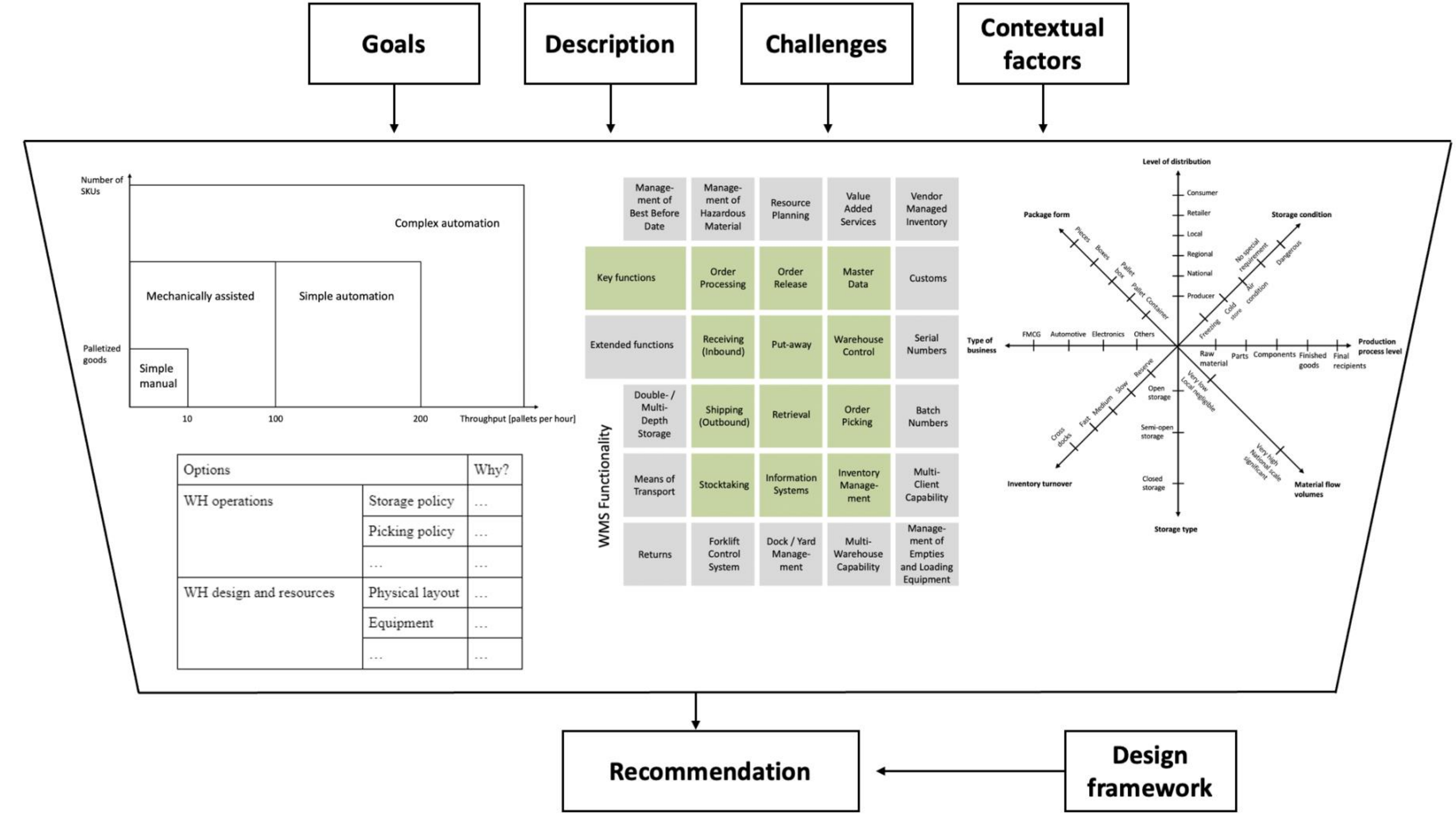

Figure 3.12 - Analytical framework

4. THE CURRENT STATE OF ALFA LAVAL

This chapter will present the current coil warehouse situation at Alfa Laval. In the first subchapter, the overall context and goal of the warehouse is described. The second part describes the design of the current warehouse, where the facilities are placed and how the coils are stored within them, and which resources the warehouse has at its disposal. The third part describes each of the steps in the operation of the warehouse. In the final part the identified challenges with the current situation.

4.1 Context and goal of the warehouse

The warehouse that is within the scope of this thesis is categorized as a production warehouse. The purpose is to store raw materials, which in this case is limited to coils, to be used in the manufacturing process of sheets, that are components of the heat exchangers. The coils are received from suppliers located in the U.S.A., Europe, Japan, and Korea. Storage wise, the warehouse situation has received little focus up until recently and the overall configuration is very basic and a result of small hot-fixes and reactive work.

The production connected to the coils consists of three different production lines with different capacities, such as which coil diameters the machine can handle. What is planned to be produced is communicated approximately a week in advance, but there are also changes to the schedule after this. The production lines are fed with coils to cut and punch them into different sheet variations. The general case is that the coil is used completely in the production. If this is not the case, the coils are placed in a designated space next to the machine to be retrieved and re-stored by the warehouse employees.

One goal of the new warehouse design is to increase the space utilization. The management's view upon the current situation is that the coil storage occupies too much space and needs to be done more efficiently. The coil storage is occupying a lot of horizontal space and taking up almost no vertical space. Another goal of the new warehouse design is to enable more efficient handling processes. Currently, to conduct a coil pick requires a lot of time and excessive steps between the retrieval from the actual warehouse and input to the production machine. In addition to this there is also a goal of increasing the quality of operations in the new design. Some coils have a very long lead time which becomes an issue when a coil that is scheduled to be used is found damaged after being stored outside and not checked upon arrival. The use of certain coils in the nuclear industry also emphasizes the need for better quality and control of the operations. Lastly, Alfa Laval has a general focus on improving the safety for their employees. This is done by aiming towards using less trucks within their warehouse and production facilities.

There are approximately 140 different variations of coils stored in the warehouse, and the total number of coils in stock is on average 650. The coils can be classified into two groups depending on their material type which is either stainless steel or exotic materials, such as titanium. This will have an impact on which supplier that supplies the material, and therefore the lead time will also differ between the materials because of the global supplier base. Some of the end-products are also used in special industries such as the nuclear industry and therefore have additional handling requirements. The coils designated for the nuclear industry have special quality requirements and are inspected together with the quality department on arrival. There are also coils that are equal to other coils but are requested by customers to be used for specific orders and therefore also require special handling. The value per coil is very high in the warehouse with the average value per coil of 184,000 SEK. This can be divided into 100,000 SEK per stainless steel coil and 280,000 SEK per exotic coil.

At first glance, the coils look very similar in terms of dimensions where all are a round cylinder fitted on a pallet. However, there is a large variety of dimensions of the coils in the warehouse. The width of the coils ranges from 40 mm up to 750 mm where certain standard widths exist. Because of the coils being ordered in terms of weight and stocked in terms of the corresponding number of sheets there is no standard diameter. This is instead limited by the production machines which have an upper limit of the coil diameter. This means that the varying diameter together with the coil width results in a significant tipping hazard. Weight wise, the coils are very heavy with the heaviest coil being up to 4 ton. A majority of the coils however are within the range of up to 2 ton. The distribution of different widths and weights for the coils can be seen in Figure 4.1 below.

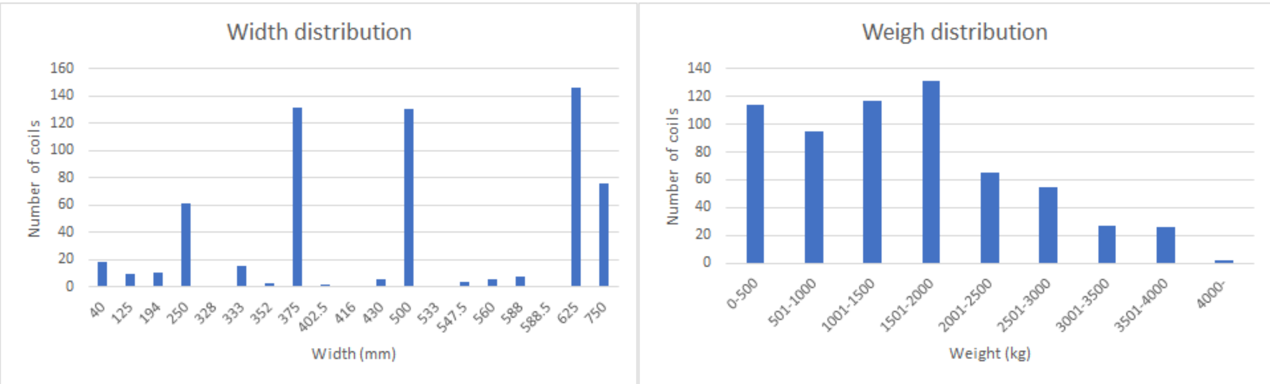

Figure 4.1 - Left: Width distribution; Right: Weight distribution

The picking data for the last 12 months shows that there is a large difference in the number of picks performed per coil. A very small portion of the coils, the top four in terms of total picks, stands alone for almost 20 % of the total number of picks. It can also be noted that the top 20 % of the coils stand for approximately 60 % of the total number of picks. The distribution of picks versus coils is presented in Figure 4.2 below.

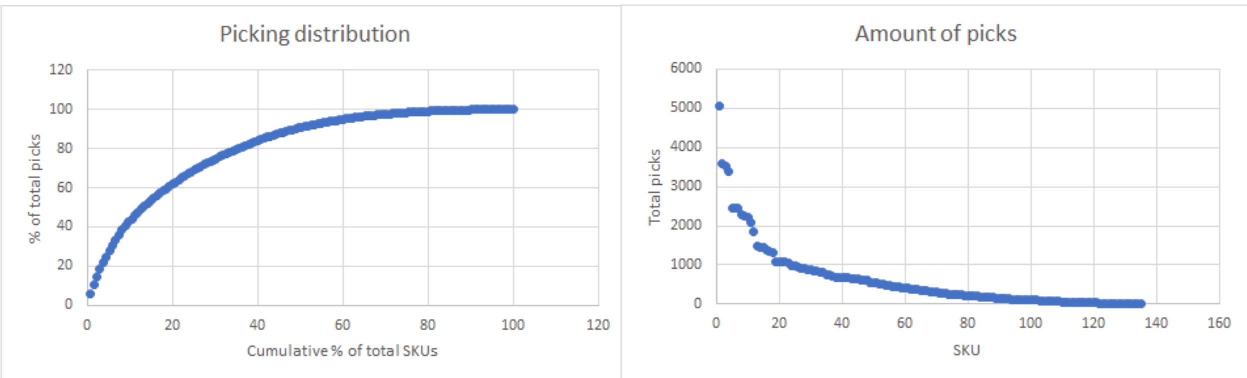

Figure 4.2 - Left: Cumulative percentage of picks versus SKUs; Right: Presentation of total picks for each SKU during a year

Looking into seasonality, the flow of picking orders is quite even throughout the year. The only deviation on a weekly basis is during the Christmas holiday where there is a decline which is then followed by a short increase during the first weeks of the new year. There is also a decline in orders during March. The seasonality data for both weeks and year is presented in Figure 4.3 below.

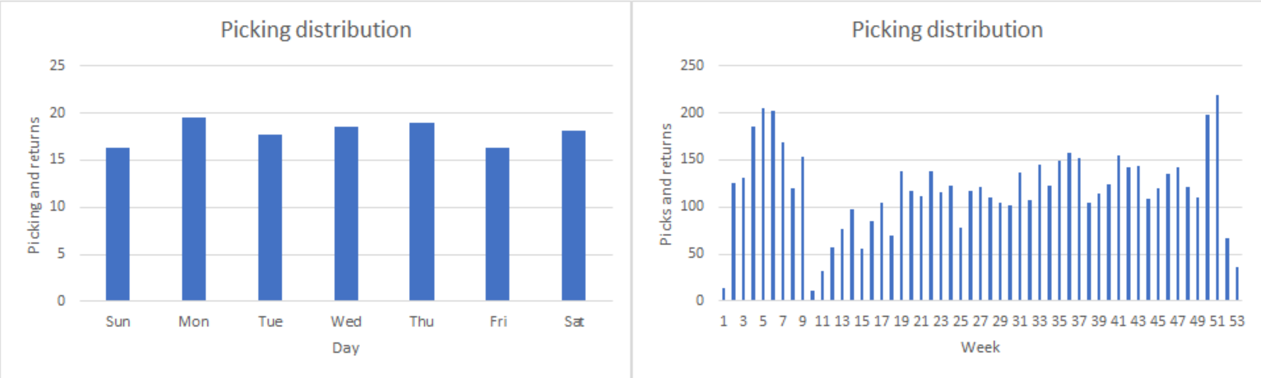

Figure 4.3 - Left: Seasonality of picks on a weekly basis; Right: Seasonality of picks and returns on a yearly basis

As a concluding remark of the collected coil data some information regarding the basic flow of the coils are presented in Table 4.1 below. This includes the average and peaks of coil deliveries and picks.

Table 4.1 - Coil data of deliveries and picking

	Average	**Median**	**Peak**
Delivered coils per day	10	12	44
Picked coils for production (including returns)	18	17	40

4.2 Warehouse design and resources

4.2.1 Physical layout

The warehouse layout consists of three different facilities as well as a storage openly in the yard, all of which together with their geographical location can be viewed in Figure 4.4. The first facility is a tent, from now on referred to as Tent 1, and is located next to the production building. This is the main storage facility that is being used for coil storage. The next facility is also a tent and is referred to as Tent 2. This is located approximately 200 meters across the yard from the entrance to the production building. The third storage area is located next to the production machinery within the production facility and is referred to as the coil stock area and consists of one aisle. This aisle consists of 21 lanes on the floor where on average two coils can be stored in each lane. The coils are stored directly on rubber blocks in this area, instead of on pallets which they are in the other areas. In addition to the three facilities there is also storage present openly outside in the yard. There are both SKUs stored outside the walls of Tent 2 as well as in a separate location referred to as Yard Storage (YS). The area where the SKUs are prepared for either production or re-storage is the Packaging Area (PA) in the figure below.

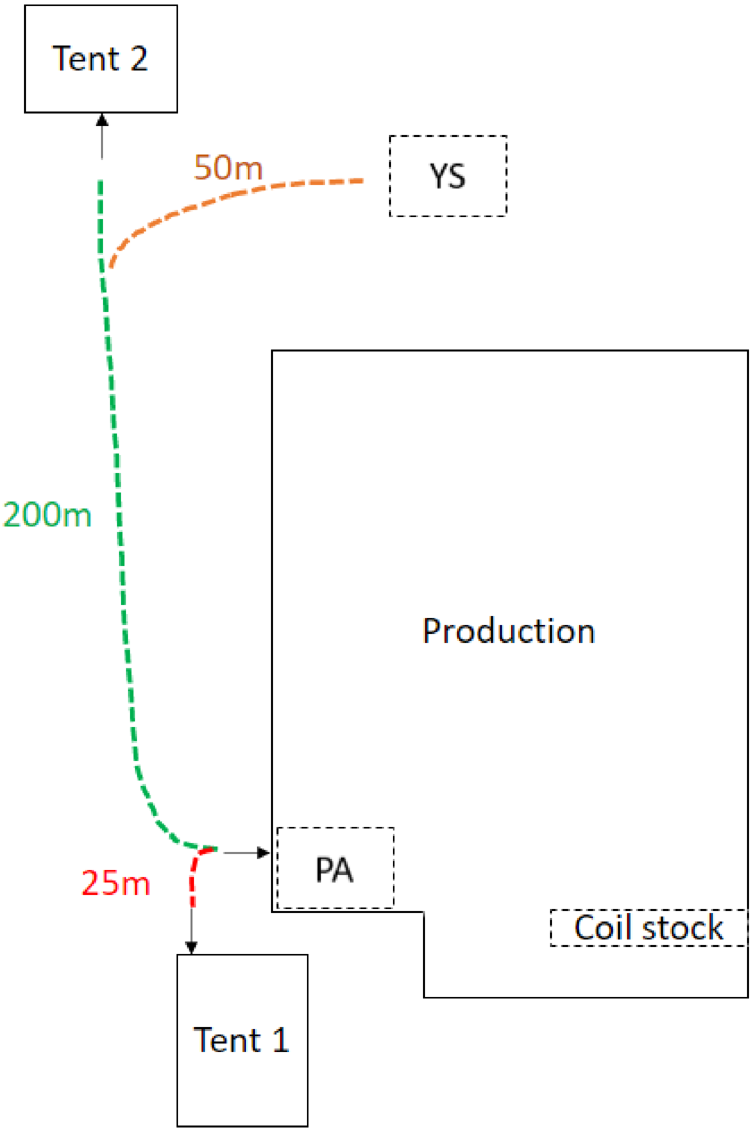

Figure 4.4 - Layout visualization of the location of storage facilities

Tent 1 has two access gates which are located on opposite sides of the building. However, only the gate located towards the production is being used which indicates a primarily U-flow configuration, in contrast to the flow-through layout. The overall warehouse dimension is long and narrow. Inside the building, the coils are stored on the ground with approximately 3-6 deep lanes, depending on the size of the coils. These lanes are arranged in a locally called, “sun fan-formation”, to facilitate the access of the coils by minimizing the sharp turns needed by fork-lift drivers. This refers to the lanes being angled towards the access gate used. The warehouse uses a single aisle which is arranged like a circle with storage lanes on both sides of the aisle, both next to the walls and in the middle of the tent. The only space which is not allocated to storage is an area next to the entrance gate. This is allocated to receiving goods from suppliers and can be seen as a receiving dock. A simplified visualization of the layout in Tent 1 can be seen in Figure 4.5 below.

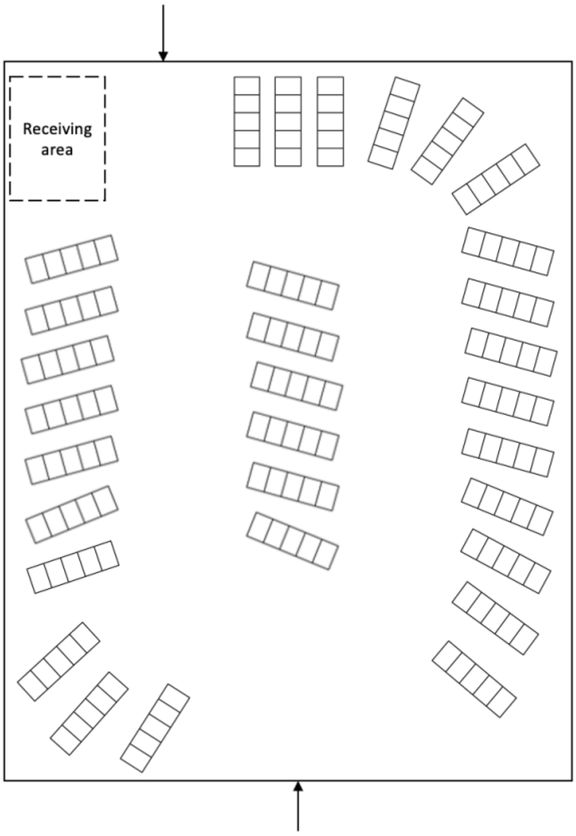

Figure 4.5 - Illustration of the layout in Tent 1

Tent 2 is smaller in comparison to Tent 1 and is located further away from production. This facility is not only dedicated to coil storage but is instead shared with sheets. The tent has no clear aisle or layout configuration but can instead be viewed as an ad-hoc layout where goods are stored where free floor space is present. This facility only has one entrance gate, and it is located in the middle of the widest side of the tent. There is one storage rack in use although the majority of the coils are stored using floor storage. The rack is placed alongside the short side of the tent and is shared by both coils and sheets. The floor in Tent 2 is a cast concrete slab, in contrast to Tent 1 which is placed directly on the existing asphalt.

Lastly, the open yard storage consists of straight lanes outside the walls of Tent 2 as well as at the separate YS. The YS area is a marked area with associated lane positions marked in the asphalt. The approximated storage area and locations available are presented in Table 4.2 below. Because of the yard storage having no area limitations it is not included in the table. At the other facilities the storage locations are approximated using the average coils per lane.

Table 4.2 - Approximated size and number of storage locations

Facility	**Area**	**Storage locations**
Tent 1	1200 m^2	400
Tent 2	550 m^2	180
Coil stock	175 m^2	75

Aside from these facilities the company has rented a warehouse located approximately 15 kilometers from the production to store additional coils. These are stored there because of a lack of space and can often be delivered to the production site within the same day. These coils are often slow-movers or red listed, coils with quality deviations that are unfit for usage in the production and are waiting to be sent back to the supplier.

4.2.2 Equipment

The coils are stored either by pallets or in roll blocks, where the coils are placed fixed between two rubber blocks on the ground. The palletized coils are mainly stored in floor storage, with only one storage rack existing in Tent 2. The rack consists of three levels and is single-deep. The reason for only using one rack in Tent 2 is because of it being shared with sheets, which Alfa Laval prefers to store on the ground. The fact that the floor in Tent 1 is asphalt means that it is not possible to install racks there. Because of the coils' round nature, they are not stackable on top of each other even though they are stored on pallets. It is possible to stack them if they lie down but the majority are standing up.

Because of the heavy nature and different handling units of the coils the warehouse is equipped with two different trucks dedicated for coil storage. One is a regular counterbalance truck that is used for moving the palletized coils between the storage facilities outside of the production facility and the packing area. Because of the coils being de-palletized in the packing area there is a need for another truck to handle it within the production facility, between the packing area, the coil stock area, and production. This is a beam truck, and it is equipped with a beam instead of forks to be able to pick up the coils by the bobbin, the center of the coil, and it is only able to drive indoors. Both of the trucks are equipped with a monitor where the truck driver can access the information system to retrieve the location of a coil.

In the production facility, at the packing area, there is an overhead crane. This crane is used by the warehouse workers to raise the coils that are stored with the flat surface down on the pallet. It is difficult to lay down a raised coil with the overhead crane resulting in that coils that are raised are stored in the coil stock area until they are completely used or obsolete. Previously, Alfa Laval purchased a coil turning machine. However, the coil turner was never implemented and is currently stored in the Arlöv warehouse.

4.2.3 Automation solutions

The warehouse does not currently have any automation solutions. All of the operations associated with the coil storage are done manually, either by hand or with the aid of various equipment. Management is however not discouraged in using automated solutions in the future.

4.2.4 Information systems

The case company uses Jeeves as their ERP system. Jeeves supports functions such as inventory management and purchasing. The system does not support any optimization functions connected to the warehouse and there is currently no WMS addon in use. It is only possible to track the location, i.e., which facility and aisle, a SKU is located in the warehouse. Up until recently, at the beginning of 2020, the location tracking input was done manually. However, Alfa Laval then implemented AlfaQ to better support this. AlfaQ enables the use of barcodes and QR-codes that update the change of position for SKUs automatically when they are scanned.

In addition to Jeeves and AlfaQ, there are also several excel-files in use that support these systems. These files are connected to the production planning to schedule which batches that should be produced and in which order. The warehouse employees then use a file connected to the production file to decide which coil to pick and when. This file shows how much available material the production has and what they will need in the near future. It also shows the status of the coils planned for production. This regards to if the coil needs to be picked from a tent and therefore required to perform additional activities, such as unpacking, or if it is already located at the coil stock and only requires to be picked up by the boom truck and be placed at the production machine.

4.2.5 Labor and activities

The responsibility for handling the coil warehouse was previously held by the production staff but was recently, around two years ago, transferred to the warehouse staff. Within the warehouse team there are 10 employees that are knowledgeable in how to handle the coil flow and the employees take turns in being responsible for the coils. The labor associated with the coil warehouse is therefore one full-time employee. All employees are inhouse and there is no external labor hired to handle e.g., variations in demand. The production is running all days of the week during all hours; therefore, the goal of the staff is to always have 24 hours of coil material ready for production to access. On weekdays the warehouse work is separated into two shifts, 06:00-14:42 and 14:30-23:00, where each shift is allocated to one worker. On weekends there is a single shift between 06:00-18:00. In case of changes in the production plans or other issues during the night, when the warehouse staff is not working, many within the production staff are able to supply themselves with coils from the warehouse because of previous experience. The majority of the coils should however already be placed in the coil stock area.

The warehouse has a number of additional activities. The first one is the labeling process that is performed in the receiving area upon the arrival of new coils. Other activities are done in the packing area when preparing the coils for either usage, or re-storage. These include either removal or covering the coils in plastic for protection, labeling inside the coil to keep track of the SKU information, as well as removing or putting the coil on a pallet. If the coil is of exotic material, it is also removed from the wooden box it arrived in when picked.

4.3 Warehouse operations

To be able to understand the path a coil takes from delivery to production, an overview of the different processes it needs to go through is visualized. This path is shown in Figure 4.6 and suits the majority of the coils. There are always differences between some of the coils due to special requirements from the customer or that there might be some areas more dedicated to one type of coil. These differences are brought up in the subchapters.

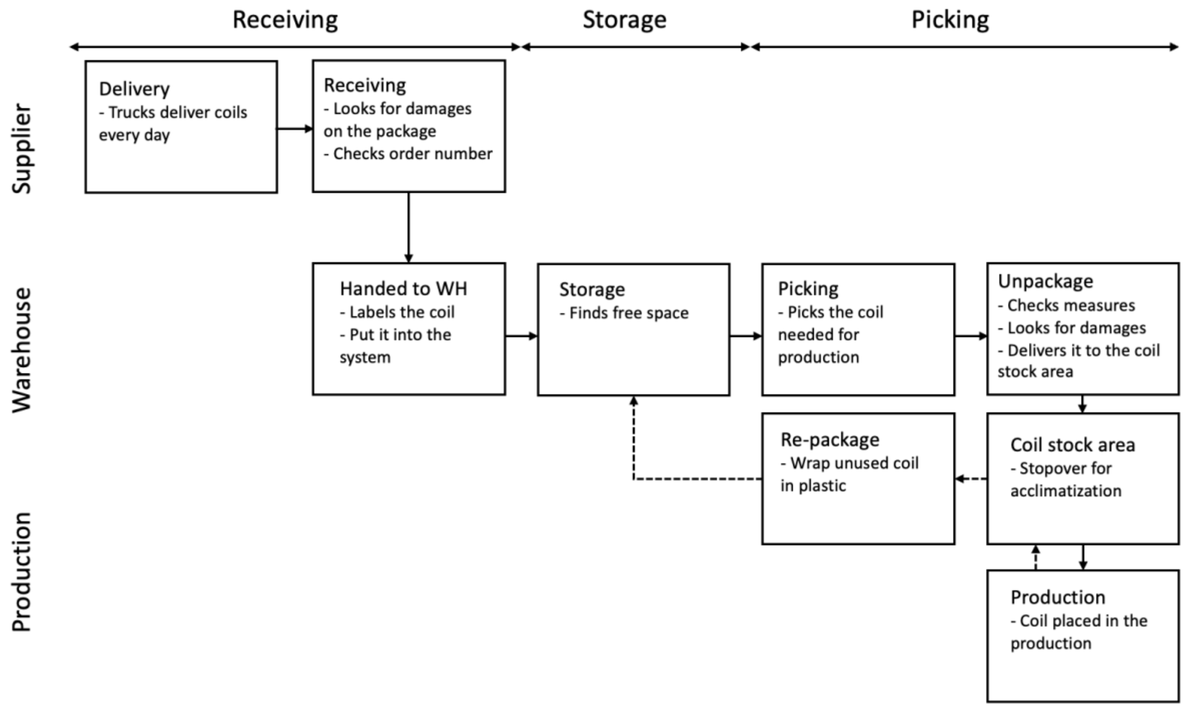

Figure 4.6 - The flow chart for the coils where the dashed lines are only used if needed

4.3.1 Receiving

The deliveries of coils to Alfa Laval are delivered by truck every day and the reception is handled by one employee. At this stage there is a quick check of the coils for damages, but this is only done visually and without unpacking the coils, i.e., the check is to see if the package is okay and not really the coils. In addition to the visual check there is a control to see if the serial number matches the order number. There is also a check to see if the ordered weight corresponds to what is stated on the physical label, but the coil is not weighed to confirm this. Shortly after this stage the coils are put into their Jeeves system, a computer system which keeps track of the inventory level and to facilitate the purchase department to see the flow of coils, and Alfa Laval's own labels are put on.

There is one main factor that affects how the coils are treated at the reception which affects how they are packaged and where they will be stored. This factor is the material the coil consists of, which is either stainless steel or an exotic material. The coils of stainless steel are more common and are received wrapped up in plastic. These coils are delivered to Tent 1 closest to the production to shorten the distance for each pick. The other coils, of exotic material, are received in wooden boxes which is better at protecting the coil but makes it more difficult to inspect them at arrival. These coils are received by Tent 2, which is placed furthest away from the production. The separation of the coils depending on the material is done to avoid mixing them together if any notes would disappear since it is difficult to visually see the difference.

Another factor affecting the treatment of the coils when they arrive is if the coils will be used for producing heat exchangers to a nuclear power plant. In these cases, the control of the coils is done more thoroughly when the coils arrive, even before they are put into the system, because of much higher requirements from the customer. If a nuclear coil arrives the warehouse staff schedules an appointment with the quality department to conduct a thorough inspection together. It is also, in these cases, important to be able to track every step of the process from the arrival of the coil to the finished heat exchanger.

4.3.2 Put-away and storage

After the coils have been received and checked quickly, they are handed over to the storage department which performs the labeling. They take the coils and put them in either one of the tents or out in the yard depending on where there is free space. Which tent to use, as stated before, determined by the material but other than that the placement is only determined on where there is space, i.e., the only policy on where the coils should be stored is wherever there is any space. The depth of each lane in Tent 1 is determined by the gut feeling and the goal is to make sure the aisles are as wide as they need to be. The result is a line depth of 3-6 coils, depending on the width of the coil, where the only accessible coil is the one closest to the aisle. When the coil has received a place, the employee scans the coil and the QR code of the lane to update the location in the Jeeves system.

4.3.3 Picking

When coils are picked for production, there is a need to plan in advance to make sure the coils which will be used have been in the coil stock area for 24 hours. The reason for this rule is based on the current storage method of storing the coils outdoors or in non-heated tents. The purpose is to make sure the coils are dry, which can take a while because the moisture can be deep between the sheets in the coil, and to make sure the temperature of the coils is close to room temperature. This is because cold and moisture coils affect the quality of the sheets negatively which can be avoided through the acclimatization. It also puts a higher strain on the production machines.

When a pick is to be executed the warehouse, employee prints a paper containing the different article numbers and quantities needed. The product to be picked is transferred to the information system in the truck by manual input, which then tells the driver which lane(s) the coil is placed at. There could be multiple coils of the same material and measurements which means that there are many results on where the coil can be found, but the oldest is the one that should be picked. This is a result of the process of FIFO which is used to make sure the coils do not get obsolete, as well as making sure that half-used coils are depleted first. Despite this method, it occurs that the coil closest to the aisle is picked instead of the oldest one or that one specific coil is not picked because it was not placed where the system said it should be. In the case when it is not placed where it is supposed could be because of manual errors or that the inventory data does not match with the reality. These errors, that probably occur due to human errors, are fixed through stocktaking two times a year.

Because of the put-away method where the coils are placed where there is space, and in front of every coil in the same line, the picking of the oldest coils has a lot of double-handling. To reach the coil that is supposed to be picked all the newer coils need to be moved from that lane and later be put back when the coil to be picked is moved. This process has sometimes resulted in that one coil could be placed in the wrong lane which makes it much more difficult to find it again and adds on even more time to the picking process.

When the coil is picked in the tent it is transported outdoors to the PA area. This transfer is done with a counterweight truck meant for outdoor activities. Here the coils are unpackaged for the first time, if they have never been used before. It is also here that the coils are controlled thoroughly for the first time to make sure the coil actually matches the description of the delivery note and that all the measurements are correct. When the inspection is finished the employee prints an approval with their name on it and paste it inside the coil bobbin. It is also in this area that the coils are removed from the pallet. If the coil is laying down it is raised with the help of an overhead crane. Afterwards, the coil is moved with the boom truck from the PA area to the coil stock area to acclimatize and when needed be transferred the last distance to the production. The whole process of picking one coil from a tent to the coil stock area is time consuming and takes approximately 25-30 minutes.

4.3.4 Re-storage

Coils that have been used in the production but were not fully used and will not be used within two days are sent out to one of the tents. To protect the coils, they are wrapped in plastic at the PA area. The plastic only covers the top of the coil and does not protect against dirt from below. The coils are also put on a pallet again and secured with small plastic straps to prevent tipping. The risk of getting dirty is higher during rainy days and the result of this could be very expensive. If one grain of sand comes into the machinery of the production of plates the punching tool could get destroyed and need to be replaced. There is one exception to the re-storage, if the coil width is 250 mm or less it is kept in the coil stock area until it is completely used or deemed obsolete. This is because of the difficulty of laying down a raised coil again with the overhead crane.

The coils are delivered on pallets which they will be stored on until they are transported to the PA area. After that, the coils are stored on rubber blocks which means that the coils that are transferred back to the tents need to be placed on pallets again. This re-usage of pallets results quite often in accidents where the pallet breaks and the coil falls to the floor, with the plastic around it, resulting in two problems. The first and most obvious one is that a coil of e.g., two metric tons is difficult to raise again from the floor because of the lack of special equipment. The second problem occurs when this coil will be used again. The plastic could have squeezed itself in between the layers of metal which would result in problems in the machine later on when it is unrolled.

4.4 Identified Challenges

The description of the current situation through interviews with relevant employees, observations of the warehouse and the working process, as well as a collection of data files has provided an understanding of the current configuration as well as the existing challenges. This understanding will be used in the analysis to see which changes that have to be made, which of the processes that are needed, and if the order of execution could be changed.

Two challenges that were identified are the double-handling and the space utilization. The double-handling is connected to the physical layout with the deep lanes, up to six coils, where it usually is one of the coils further in that is picked. The challenge with space utilization is connected to the high rate of coils stored on the ground and that some areas that can be used are not. All of the challenges that were identified are listed in Table 4.3 where they are categorized by the affected area.

Table 4.3 - Categorization of the challenges identified in the coil warehouse at Alfa Laval

Configuration element		Challenges
Warehouse Operations	Inbound operations	Small receiving area
		Re-storage of coils require repackaging
	Outbound operations	Quality checking each new coil during picks
		Picking errors
		De-palletizing coils
		Coil to be picked often require double handling
Warehouse design and resources	Physical layout	Double-handling because of up to 6 coil deep lanes.
		Unnecessary touchpoints because of the transportation in- and out-door
		The current setup with lanes does not facilitate using the FIFO method which is in use
		Low space utilization
		High risk of obsolete coils because of dirt
		Small receiving area
		Unfavorable storage conditions
	Operations strategy	Lack of storage policy
		Late quality check
		Lack of documentation of lost coils because of the reliability on the inventory control
		High stock levels of certain coils
		Lack of follow-up on KPIs

	Warehouse equipment	Need of different trucks for transportation in different locations.
		Storage on pallets
	Information systems	Lack of traceability of the coils
		Lack of information of the order specific coils in the system
		No support for storage or picking policy
	Labor	Scanning errors when coil is moved
		Does not always search for coils that are placed incorrectly
		No documentation on coils that have disappeared
		Lack of commitment to FIFO
		Lack of competences, e.g., crane license

5. ANALYSIS

In this chapter the situation at Alfa Laval is analyzed through identifying the contextual factors for this case. These are discussed and categorized with regards to their importance and impact on the new designs. Further on, the tools presented in the theory are applied to this context so that the suitable configural elements can be identified.

The first model is the functional classification and describes how complex the warehouse needs to be because of the current situation and will be a guide to the coming decisions. Alfa Laval's position can be seen in Figure 5.1 and is marked as red lines in the model. Since the majority of the lines are close to the center the warehouse does not need a greater complexity to work. The only part that stands out is the storage type where the coils need to be stored inside to avoid the factors of bad weather and to reduce the traveling distance. This is a change compared to the current storage where the coils are stored in a semi-open storage, e.g., in tents and some stored in the yard.

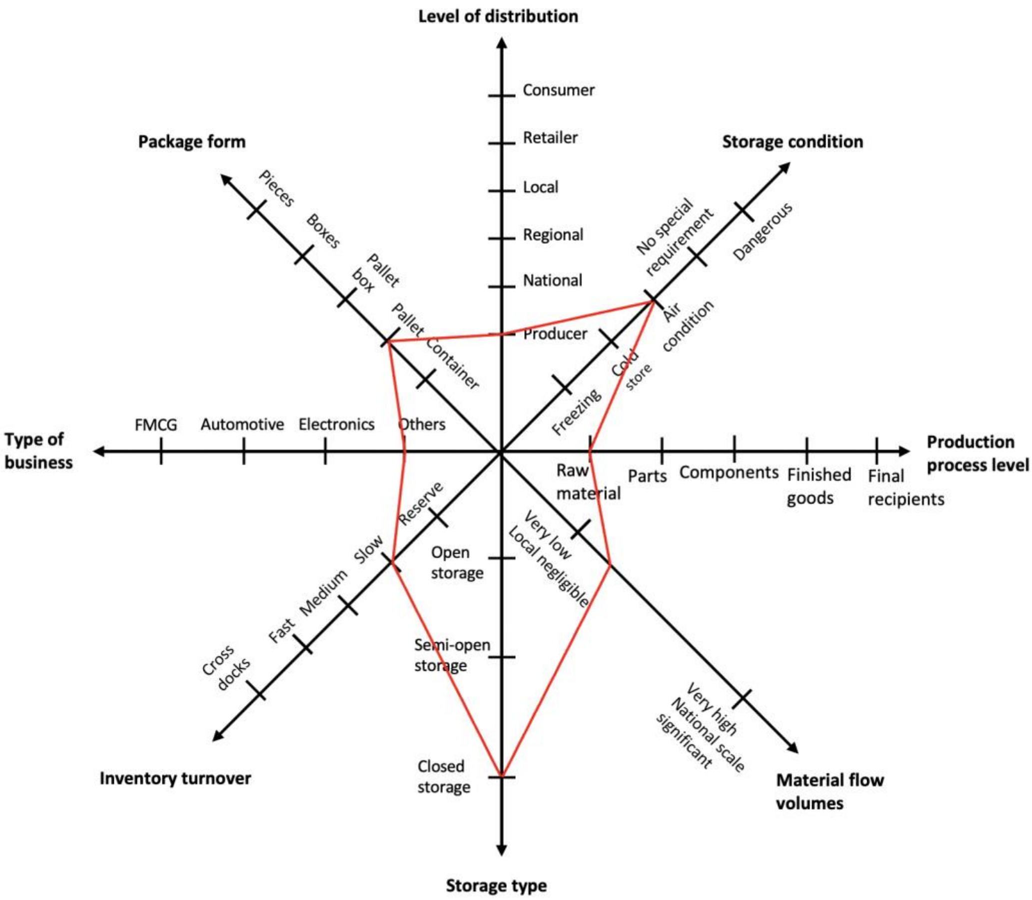

Figure 5.1 - Functional classification of the warehouse, based on (Jacyna et al., 2015; Vreriks, 2017)

5.1 Contextual Factors

Before new designs of a warehouse are produced there are contextual factors that have to be defined and included in the process. Contextual factors are factors that cannot be changed, only adapted to or avoided which makes them important to consider. As per the name, the contextual factors depend on their context, meaning that a contextual factor for one context might not exist in another. Therefore, factors that are unchangeable in one case could be changeable in a different case. To understand which contextual factors that exist in this case, the common factors described in the literature will be analyzed in the context of this thesis.

The different contextual factors from chapter 3.4 are product characteristics, order characteristics, customer characteristics, demand profile, volume profile, regional situation, physical layout, and information systems which will be evaluated to determine their importance. Each one of the contextual factors affects the configuration in different ways. The physical layout affects what proportions the warehouse could have, where the emergency exits are placed, and if the space is shared with someone else while the regional situation sets a bar on when the automated solution is more profitable, because of the difference in wages in different regions. To simplify and understand which factors to focus on, the contextual factors of this situation are categorized into *Main* and *Other,* seen in Table 5.1. The latter are deemed changeable for this context and therefore of lesser importance while the former are not changeable within this context. This reason could be because of a *Main* factor overruling the impact of an *Other* factor, or because of the delimitation of this project that some factors should not be considered. A further description of the different contextual factors and their effect can be seen in the two following subchapters.

Table 5.1 - Contextual factors in this context and their classification

Contextual factor	**Description**	**Classification**
Product characteristics	There is a medium number of coils and a large variety of dimensions. This has an impact on the storage space and the needed equipment.	Main
Order characteristics	The number of orders is low, there is one order-line per order, and one SKU per order. The impact is low since the picking possibility is determined by the product characteristics.	Other
Customer characteristics	There are both nuclear orders and special orders from the customers which demand special treatment. The impact is a necessary traceability of the coils.	Main
Demand profile	The demand is stable during the year. This results in a low need to be flexible and lowers the needed complexity of the warehouse.	Main
Volume profile	The volume is low throughout the whole day and results in a low number of employees. This removed the need to consider congestion.	Main
Regional situation	The region of the warehouse is Sweden which has a high labor cost but there is only one employee. This has a minor effect on when automation is profitable.	Other

Physical layout	There does not exist a building which the warehouse has to be within. The dimensions can be adapted to the solution.	Other
Information systems	The current information system will be changed and adapted to the needs from the new warehouse.	Other

5.1.1 Main contextual factors

The first contextual factor is the product characteristics. Since the only product stored in the warehouse is coils, and the handling unit is pallets or individual coils, the need for different equipment is reduced in comparison with a large variety of handling units. Instead, the weight and measures of the coils is important to consider. From the collected data the variety of width is large, from 40 mm to 750 mm, and there exist coils with special measures within that range. Since the coils have a maximum weight and diameter when delivered and that the coils could be restocked after usage the diameter is also of great variance. These two factors mean that the proportions of width and diameter states if a coil can stand up or has to lie down, if there is no support, and could create two different handling methods.

The second contextual factor is the customer characteristics which include the number of different customers and what their requirements are. What the customer wants affects the number of different coils there are in stock. If customers want special materials, like the coils for nuclear plants, or measurements there will be more coil varieties to track which complicates the process. There also exist customers at Alfa Laval that want their product to be documented all the way from raw material to finished product. These differences in demand affect the type of information system that is needed to enable traceability of the order-specific coils as well as how the coils can be stored.

The third contextual factor is the demand profile. From the collected picking data, it could be seen that the demand was consistent for the larger part of the year. The only two variations, which was seen in Figure 4.3, is the dip over Christmas and New Year, which probably depends on vacations, and the second dip in March. The second dip was seen with data from 2020 which also is when the Corona virus started to spread through the world. Because of this circumstance, that dip is excluded which results in a stable demand. With the stable demand there is no reason to be flexible to handle peaks which reduces the complexity of designing the warehouse.

The final factor is connected to how the volume profile looks in the warehouse, i.e., how large the flow of material is, affects the need of multiple trucks or the needed picking speed for a crane. In this case the flow of coils is low, it arrives only around 10 coils per day, and there are around 18 picks. These low volumes reduce the need of multiple workers and trucks needed which also makes it possible to configure the layout without major consideration to the risk of congestion.

5.1.2 Other contextual factors

The first contextual factor that is considered to be of lesser importance is the order characteristics. This factor consists of the number of order lines each order has and how many orders that are received and has a low impact in this context. The way it would affect the warehouse is the routing method to use but because of the product characteristics, where the size results in that only one coil can be picked per round, it does not matter which the optimal routing method would be.

The regional situation is something that is needed to consider but might not be the most important one. The result of where the warehouse is placed is the local regulations on how the work should be executed and what wages the employees have. The wage could be important when it comes to the implementation of an automated system where higher wages make up a larger saving. But in this case, there is only one employee working in the picking area which lowers the impact.

The two remaining contextual factors are the physical layout and the information system. These contextual factors are important to consider if they are defined in advance and not changeable. In this case, the physical layout will be adapted to the need of space, i.e., there might be a new building specifically for this project if needed. When it comes to the information systems the current system will be replaced with regard to the functions needed with the provided recommendations.

5.2 The contextual factors and challenges influence on the warehouse configuration

The identified contextual factors and challenges with the current warehouse configurations need to be taken into account when designing the new configuration. Therefore, below will include a discussion of how the identified contextual factors and challenges affect the different sub-areas within the configuration. This will include which challenges that need to be reduced, different suggestions on how they are reduced, and how they are affected by the contextual factors. The different configural decisions presented in the theory section will be discussed and summarized under each configural area.

5.2.1 Operations

From the mapping of the flow of one coil, from receiving to production, the different operations in the process were examined. It was noticed that many operations took time, created unnecessary touchpoints, and were sometimes placed in an illogical order.

The first challenge is connected to both the receiving and the picking of the coil and is the late quality inspection. When the coils are received the only control made is if the package is undamaged and that the serial number matches the order number. Even though there exists time in this phase, the coils are only placed in the storage without any further examination. The sufficient inspection is instead performed in the picking process where the time for each pick should be as short as possible. This placement increases the picking time and the risk of having a delayed delivery to customers because of the long delivery times of new coils if any problem would appear.

The second problem noticed is the number of non-value adding activities and unnecessary touchpoints. One area which contains many of these stops and activities is the PA. It is there the coils are de-palletized when they are picked from storage to production as well as palletized when they go back to storage. The coils are also unpackaged and repackaged in this area which has to be done to protect the coils from the current storage conditions. Another area where non-value adding activities are common is in the storage. There exists a lot of double-handling which is a result of the combination of deep lane storage, the put-away strategy to place the coil at the first free spot, and the FIFO method. This double-handling consists of moving coils which block the coil that should be picked, resulting in both movements to access the coil but also to return the moved coils.

The third time-consuming activity does not require any labor activity but ties up capital and makes the process less flexible. This is connected to the need of the coil stock area and is a result of how the coils are stored earlier. Because of the uninsulated tents and that the properties of metal change with temperature the coils are too cold for production when they are picked during cold days. Another reason is that the coils get moisture when stored outdoors which they cannot be during production. Storing the coils in the coil stock area removes these problems but makes the production less flexible because the production needs 24 hours to make any changes in the production flow, if they stick to the existing guidelines, and ties up unnecessary capital during that time.

These challenges can be removed by a combination of changing the order of operations, how the coils are stored, and the picking method to suit the situation. To begin, the control of the coils delivered should be moved from the picking to the receiving process. That change results in a shorter picking time and decreases the risk of delays in deliveries to customers because of the increased time to receive a new coil if needed. On the other hand, this adds an extra moment by unpacking and repacking the coils to make the control before storing them in the tents. If the storage area is changed to be indoors this extra step is removed and will also remove the challenge with the need of the coil stock area to acclimatize the coils. These changes can be seen in Figure 5.2 where steps that are removed from the old process have a red cross and steps that change order or are added to another step are marked with a red frame and an arrow to where it should be placed.

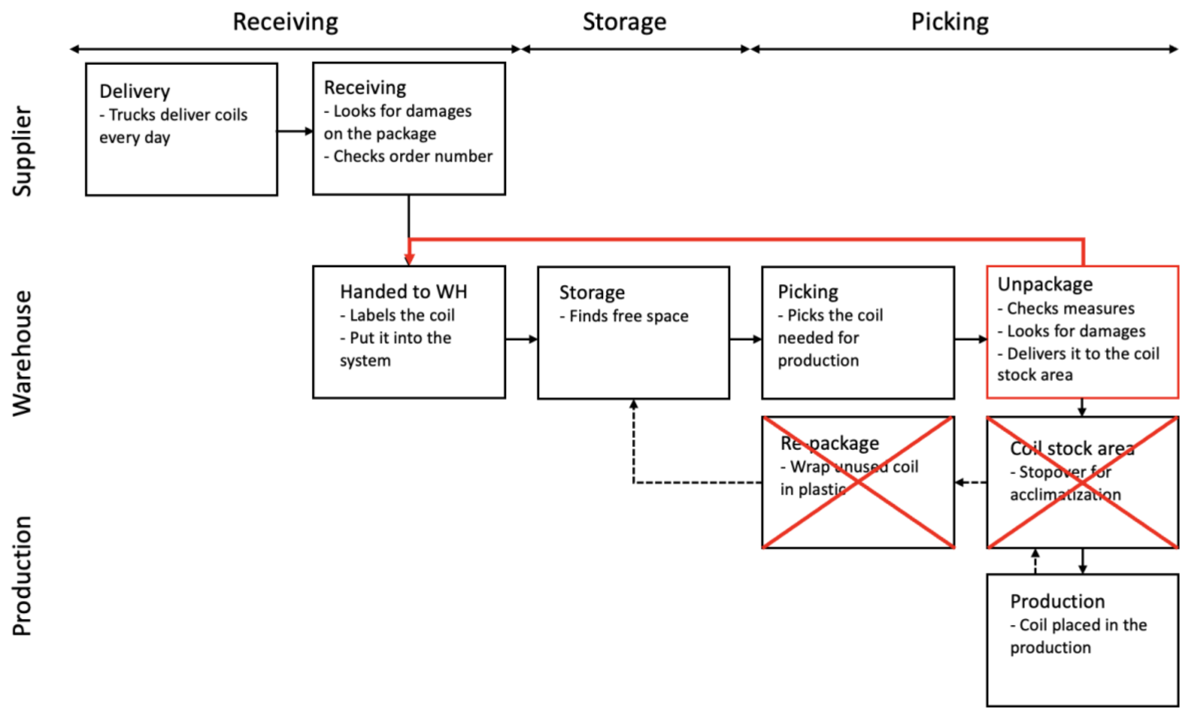

Figure 5.2 - The old flow chart with markings on the changes in the process

In addition to the changes in the process order the storage policy, picking strategy, and the picking policy should be changed to be more suitable to the situation. With the picking frequency of the different coils in mind and how they are handled, e.g., if they can be seen as pallet-loads or less than pallet-load, the suitable storage policy can be decided. From the different alternatives in Table 5.2 the most suitable is the class-based storage policy. This is in line with the popularity distribution of the coils. The picking strategy which suits the situation best is the serial picking strategy which is when one employee picks the whole order. This strategy suits the situation best since the number of picks corresponds to no more than one person's work. The final configuration area is the picking policy and states how the different products shall be picked and in which order. The single-order policy suits the situation best and is highly connected to the product characteristics. Since it is only possible to pick one coil per pick the batch picking policy is not possible to perform which also makes the routing unnecessary. The only way to make a pick is to drive to the coil, pick it, and drive back to the production.

Table 5.2 - Decisions suitable for the case company within warehouse operations

Configuration area	**Sub-area**	**Reason**
Storage policy	Shared storage	Places SKUs randomly and enables higher space utilization, but with the downside of greater travelling distances
	Dedicated	Allocates locations for special SKUs of e.g., heavy weights, but with the downside of lower space utilization
	Class based	Suitable for large differences in SKU popularity.
	Family grouping	Enables similar SKUs that are requested together to be stored next to each other.
	FPA	Many popular, less than pallet-loads, orders
Picking strategy	Parallel	Multiple workers per order (requires sorting)
	Serial	One worker per order (requires no sorting)
Picking policy	Single order	Few orders with many lines each
	Batch	Many small orders with few lines
	Routing	Minimize traveling distance per pick

5.2.2 Physical Layout

The physical layout of the warehouse can be divided into decisions regarding the space utilization, flow configuration, and aisle configuration, which was discussed in the theory section. One of the main challenges with the current situation, and also a goal to increase, was space utilization. In contrast to the ways presented in the theory of how to increase space utilization, Alfa Laval does not utilize the available height, instead very deep lanes are used to be able to fit the coils. The poor space utilization has also led to ad-hoc solutions with unsuitable storage conditions in tents as well as under open sky. This is not aligned with the contextual factor of customer characteristics, where special requirements on cleanliness are important. The tent storage and outside transports results in high risk of dirt in the coils as well as moisture which could result in coils being rejected by the production machine. To facilitate the customer requirements outside transports and tents should therefore be avoided.

The second decision regards the flow configuration and where the receiving and shipping area should be located. With the current situation there is no clear categorization of how the flow is configured. The coil is taken through many points at different locations throughout the site between receiving and production. If the space utilization is increased and the coil storage points are consolidated, a clearer flow configuration can be achieved. This is affected by the volume characteristics which in this context is very low. There is only one employee working and the number of coils that are received and picked is low. This argues for using a U-flow configuration because of the non-existing risk of congestion. The setup is also suitable for this context because of the coil popularity distribution. Few coils stand for a large portion of the total amount of picks which aligns with the U-flow configuration making a few storage locations very convenient. However, with the coils being recommended to be stored and transported inside only, a flow-through configuration is possibly required. This is because of the delivery of coils coming from outside the factory whereas the coils are then used inside the factory.

The last decision area regards the aisle configuration. With the volume characteristics of low flow as well as the goal of high space utilization, few aisles are favorable. This would increase the number of storage locations per floor space without imposing a risk for congestion. A common approach is to introduce many aisles and cross-aisles to be able to reduce travelling distance from one pick to another. This is not suitable for this context where it is only possible to pick one coil at a time because of the product characteristics. By using the tool presented in the theory with regard to the physical layout a summary is presented in Table 5.3 below. Selected decisions are marked in grey.

Table 5.3 - Configuration decision of physical layout

Configuration area	**Sub-area**	**Reason**
Space utilization	Floor storage	Cheap
	Rack storage	Increase volume utilization
	Lane depth	Increase space utilization with deeper lanes
Receiving and shipping location	Flow-through	Many locations with good accessibility
	U-flow	Few locations with great accessibility
Aisle configuration	Many aisles	Less congestion

	Few aisles	Higher space utilization
	Cross aisles	Reduces travel distance for multiple picks

5.2.3 Equipment

Challenges related to the equipment used were connected to the floor storage with deep lanes which led to a lot of double-handling occurring within the warehouse. This setup resulted in poor space utilization and issues with following the FIFO policy. As stated in the previous subchapter, a version of rack storage should be implemented to address the challenge of poor space utilization, which also is a goal of the new design. Connected to this is the decision of the depth of the storage rack. By using single-deep the accessibility is increased by enabling every location to be independently accessible which would also reduce the double-handling. In addition to this, the difficulty of following FIFO would also be addressed. The employees were more incentivized to pick the coil closest to the aisle because of the oldest coil being located deeper within the lane by logic. By enabling FIFO to be more properly followed, the occurrence of several half-used coils of the same article would be reduced, which in turn would increase the available capacity in the warehouse. Lastly, the storage of coils in single-deep racks supports the traceability challenge. Instead of only tracking locations by lane it is now tracked by each individual location which enables better traceability of the exact position of each coil.

However, the single-deep storage would require more aisle space to access the pallets which is against the goal of increasing the space utilization. By using multi-deep rack storage, the space utilization would be improved by having every lane individually accessible so that fewer aisles are needed. To both address the challenges reduced with the single-deep lanes as well as the space utilization, a combination of single- and multi-deep storage would be preferred. The issues of double-handling and following of FIFO would be reduced by only storing the same articles in each of the lanes. The storage equipment decision tool presented in the theory is visualized in Table 5.4 below, with the preferred mixed setup marked in grey. The bottom four variations are summarized as one and are not recommended. This is because of the product characteristics of this context as well as the available market solutions.

Table 5.4 - Storage equipment decisions

Type	**Description**	**Advantage**	**Disadvantage**
Single-deep rack	Store's pallets one deep	Every pallet is independently accessible	Require more aisle space to access the pallets
Double-deep rack	Store pallets two deep	Every lane is individually accessible, requires fewer aisles	Risks double handling because of LIFO, requires a special truck to reach
Other versions of multi-deep rack	...	...	...

One of the challenges identified related to the equipment was that the warehouse employees needed to frequently change trucks during the processes. This is because the flow upstream from the PA is handled on pallets, while the downstream flow is handled without pallets. This results in an unnecessary non-value adding time for the operations and a disruption to a continuous flow which should be avoided. To be able to avoid this challenge there is a need for a uniform way of storing and handling the coils. Storing on pallets was another identified challenge. This was because of the pallets breaking and resulting in difficult operations to raise the coils from the ground. The warehouse employees also felt that handling the coils without pallets was much easier because of avoiding the tipping hazard when transporting. Therefore, the aim should be to handle the coils without pallets during all processes. This will also eliminate the need for the truck equipped with forks and only a single truck type is needed.

Another challenge related to the equipment was the difficultness of raising and laying down coils with the overhead crane. Alfa Laval previously purchased a coil turner which was never implemented. By using this machine instead, the safety of the turning process could be improved.

Specific coil storage equipment

Alongside the data collection related to the current situation at Alfa Laval additional information regarding different storage equipment suitable for coils were collected. These suppliers were identified through searches on the internet and the data regarding these solutions were collected through e-mails, virtual meetings, and phone calls. The identified storage equipment is discussed below.

The market has, in comparison to goods stored on pallets, a limited amount of storage equipment available for coils. One solution is a modified rack storage that is fit for coils instead of pallets on each level, see Appendix B. However, these rack types require different sections for different widths and with the product characteristics this results in a difficult setup. On top of the very limited range of widths that can be stored in each section, there is also a requirement on the diameter to width ratio because of the tipping hazard of the coil which makes some coils unable to be stored in this equipment. Even though the product characteristics implies several standard widths there is no standard diameter which makes these downsides significant. To address this there are also other solutions, see Appendix C, which eliminate the need for width specific sections. However, the width to diameter ratio is still a requirement and the solution is only suitable for coils above 500 mm in width. With the product characteristics this means that a separate equipment and storage method is needed for at least a third of the coils. Both of these solutions are, because of the weight of the coils, only available as single-deep.

Another solution is a modified version of the cantilever rack, see Appendix D. In contrast to the equipment above, the cantilever suits the product characteristics by enabling storage of any width and diameter to width ratio. It is also possible to use it both as single and multi-deep storage, depending on the width of the coil and storage arm. This enables a balancing of the space utilization gained by storing coils of the same article multi-deep, while ensuring accessibility for other coils in single-deep lanes.

A different equipment option is the usage of overhead cranes, see Appendix E for an example setup. These enable better space utilization on a horizontal level because of the elimination of aisles. However, since the product characteristics of the coils implies that a large portion of the coils are unable to stand without support it is less possible to stack the coils on top of each other. This will decrease the vertical space utilization which is a challenge with the current situation. A challenge this equipment type will help to reduce is related to the picking errors and incorrectly placed coils. By using an automated crane these human errors are avoided. There is also a gain in the safety of using this solution compared to the rack storage because of the reduction of truck usage and human travel within the coil storage area. It should be noted that using this solution implies risks associated with crane malfunctions where no coils are accessible which stops the production at the factory.

To be able to select equipment which provides value compared to the effort of implementing it, the impact effort matrix is a valuable tool to use. The matrix with the four different solutions inserted can be seen in Figure 5.3. The solutions are numbered 1 to 4 where 1 stand for the rack in Appendix B, 2 stands for the modified rack in Appendix C, 3 stands for the cantilever solution in Appendix D, and 4 stands for the overhead crane in Appendix E. Equipment type 1 and 2 has less impact and more effort required to implement in comparison to the other equipment types. This is based on their need for several different storage methods to be able to handle the contextual factors. Equipment type 3, the cantilever, has less effort and greater impact because of the uniform way of handling all coils regardless of the product characteristics. Finally, equipment type 4, the overhead crane, has a similar impact in comparison with the cantilever but within different areas. Instead of enabling the smallest footprint, the overhead crane compensates its impact through e.g., improvements in safety and picking errors. On the downside it requires ore effort to implement because of the large difference in development in comparison with the current situation.

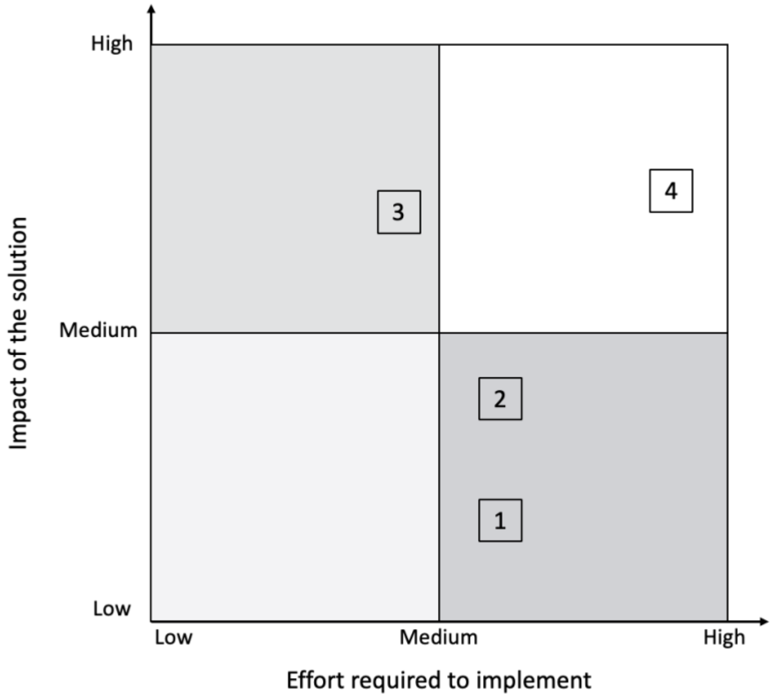

Figure 5.3 - The placement of the four different equipment in the impact effort matrix, based on (American Society of Quality, n.d.)

To summarize the different equipment types available as well as their advantages and disadvantages considering what challenges they tackle and how they are affected by the contextual factors, a summary is presented in Table 5.5 below. The preferred equipment types are marked in grey.

Table 5.5 - Summary of evaluated equipment types

Equipment type	**Advantages**	**Disadvantages**
Modified storage racks	• Increases space utilization • Increases accessibility • Reduces double-handling and associated picking errors • Better supports FIFO	• Does not support all width and diameter types • Requires many different sections
Cantilevers	• Supports all different coil widths and diameters • Increases space utilization • Increases accessibility • Reduces double-handling, and associated picking errors • Better supports FIFO	• More difficult to retrieve and put-away coils

Overhead cranes	• Safety • Eliminates manual picking errors and incorrect placements • Increases accessibility • Better supports FIFO	• Most expensive • Small widths require additional support • Difficult to stack because of the product characteristics

5.2.4 Automation

The product characteristics of this context are in an automation perspective very similar if one considers the shape and type of SKUs only. There are only coils handled, which can have a uniform handling unit, in contrast to e.g., spare-part warehouses which handle very different types of SKUs with different handling methods. As brought up in the theory section, automation is very appropriate for conditions with few changes in product requirements where the solution can perform a specific task which it was designed for. However, the contextual factors related to volume flow show that the number of coils handled in the warehouse is relatively low. It was also identified that the throughput of coils was low, only around 28 per day on average. According to the automation assortment tool, presented in Figure 5.4, this does instead argue for a mechanically assisted warehouse. It should be noted that there are more aspects, such as the goals of the design, to consider than just the number of SKUs and throughput.

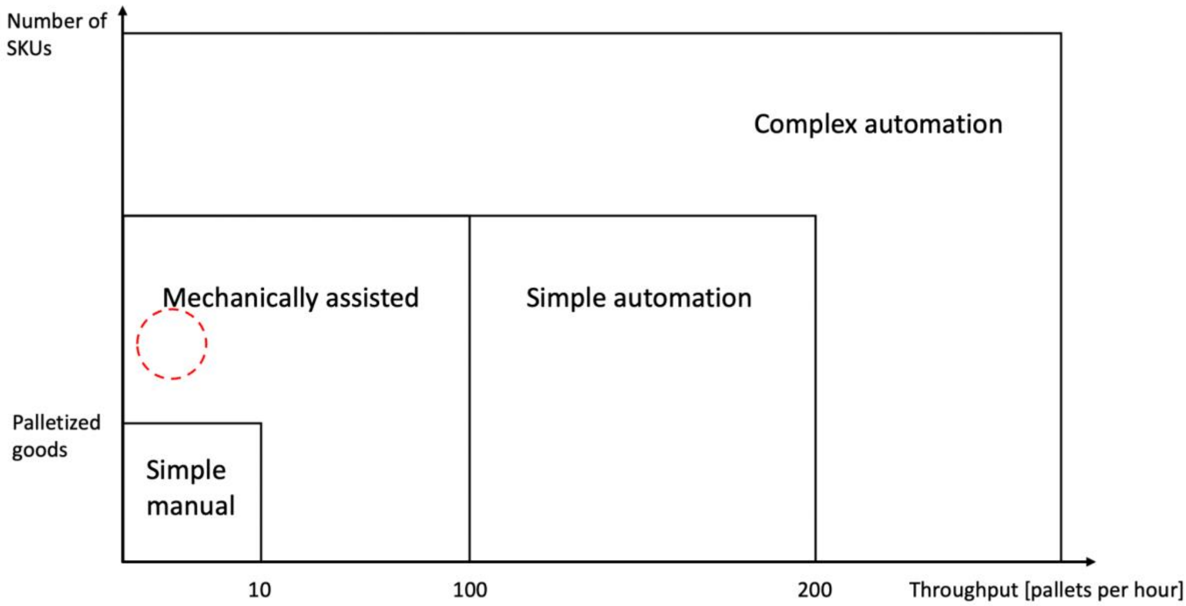

Figure 5.4 - Placement of the case company in the automation assessment tool, based on (Naish and Baker, 2004)

By using automated solutions, it is possible to address challenges related to the current situation. There are currently issues regarding manual errors such as forgetting to scan the coil when changing location, and challenges related to following the FIFO policy. An automated system could also increase the safety of the operations. Since automation also requires a variation of an information system, many challenges related to this can be solved in a combination of them. These will though be discussed under the next subsection.

5.2.5 Information Systems

As discussed in the theory section, information systems have potential in improving the processes at a company by using various tools connected to them. This is not something the case company is currently taking full advantage of. The only function that can be compared to that of a WMS is the AlfaQ which supports the tracking of aisle locations. Out of the identified challenges in the previous chapter there are many that can be connected to the lack of a WMS. Alfa Laval experienced issues regarding the random placement coils which led to non-optimal placements which affected both the handling efficiency in terms of double-handling as well as the space utilization. Continuing on the space utilization, this was also experienced as a problem because of the company not adhering to the FIFO method in the picking process. Since the employee could decide on which specific coil to pick, it was often easier to pick the newest coil that was located closer to the aisle instead depleting the already used coil to free up a storage location. Another challenge was connected to the customer characteristics and the traceability requirement of order-specific and nuclear coils. This was something that lacked rigid processes and proper system support and led to order-specific coils being used by other orders than the one they were dedicated for.

Many of the challenges can be reduced by implementing functions that support the processes in the coil warehouse. By supporting storage policies, the warehouse can be adapted to its context and product characteristics, such as width and weight, can be accounted for when deciding on the optimal storage location for a coil. Picking policies can improve the space utilization by enabling the FIFO to be properly followed. Overall, by introducing more rigid and set working processes and policies there will be less room for manual errors occurring because of the ad-hoc or random current processes. The implementation of a WMS also supports the contextual factor of customer characteristics. By having more control over exact storage locations in the warehouse and where coils are placed it is possible to facilitate the requirement of traceability.

Disconnected from the solutions on how to adapt to the challenges on a process level, a WMS also enables better support for master data. This issue was discovered during the data collection phase. Alfa Laval lacked adequate information regarding the warehouse on a coil or pallet level. The coils were ordered in kg and stock kept in pieces of sheets that the coils corresponded to. With more adequate information regarding the coils in stock, and therefore also the number of storage locations needed, it ensures better control over the warehouse capacity. Together with one of the benefits mentioned in the theory, that WMS leads to more trustworthy and higher quality of the information, it is also possible to solve the reason for not following up on Key Performance Indicators (KPIs) connected to the warehouse.

As a summary, the specification of which WMS functions that are missing with the current information system setup, which assists in reducing some of the existing challenges at Alfa Laval, is presented in Figure 5.5 below. In addition to the described challenges and functions earlier in this subchapter, multi-depth storage is also included. This function will facilitate the use of multi-depth storage and the goal of space utilization.

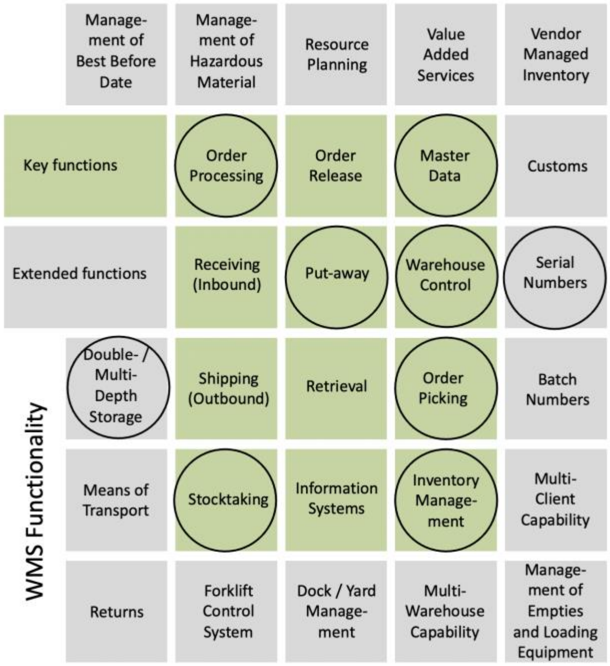

Figure 5.5 - The different WMS functions needed, based on (Nettsträter, 2015)

5.2.6 Labor

The challenges related to labor were that the employees forgot to scan coils when they were moved. This resulted in incorrectly placed coils which then went missing and this was a challenge when the coil was supposed to be picked but not found. In this case, low effort was made to search for the missing coil and there was no documentation done with regard to which coils that were missing. There were also challenges related to commitment to FIFO, where a coil that was more accessible was picked instead of the coil that was already half-used. In addition to this, the challenges mentioned can be related to the contextual factor of customer characteristics. This factor highlights the importance of traceability within the coil warehouse for the order-specific and nuclear coils. By addressing these challenges, it is possible to adjust to the customer characteristics of this context.

The importance of reducing labor costs was discussed in the theory section. In this context it is of lesser importance because of the relative lack of labor-heavy tasks. The operations are handled by one employee implying that the labor costs in absolute numbers associated with the coil warehouse is low. On the other hand, the main focus is then to optimize the handling processes to achieve more efficient handling, higher quality of operations, and better space utilization, rather than aiming to cut labor costs. Since one of the goals of automation is to eliminate expensive labor costs this is also something that argues against automating the processes. In this context an automation would not eliminate the existing one employee since the need of being the interface between production and the warehouse still would exist, at least part-time.

With the volume characteristics of this context there is no need for either temporary worker or flexible contracts. Even when considering the rare peaks these are still manageable by one employee. However, job rotation is something that is currently used with the coil responsible employee being rotated from the larger pool of warehouse workers. This creates flexibility by having many employees that have the knowledge and are capable of operating the coil flow. This would also serve as a potential labor management tool if the volume characteristics changed in the future. Another way of ensuring flexibility is enabled by the demand characteristics. The production line implies a limit on only three coils that are needed at a time and the picks per hour required is very low in comparison to other industries such as Fast-Moving Consumer Goods (FMCG). This makes it possible to do work-load balancing by postponing the put-away of deliveries and picking and orders for when it is more suitable. The suitable labor management methods are marked as grey in Table 5.6 below.

Table 5.6 - Methods of handling demand variations

Area	**Method**	**Description**
Labor management	Temporary workers	Flexibility on number of full-time employees
	Flexible contracts	Flexibility on working hours
	Job rotation	Flexibility on number of employees at different functions inhouse
	Work-load balancing	Flexibility by postponing orders to get an even flow

5.3 Summary of findings

Through observations, interviews, and quantitative data several challenges with the current warehouse configuration were identified. These were then discussed under the different sub-configural areas in the previous subchapters, both with regards to the current challenges as well as suggested changes. This part will serve as a summary of the most impactful challenges, where some challenges are merged together for simplification purposes.

The first major challenge is related to the many different touch points existing with the current coil flow. Between the physical storage and the production machines there are both the PA, where the quality check and additional activities are performed, and the coil stock, where the coils are temporarily stored before consumption. These unnecessary touch points do not provide any value but rather prolong the time between retrieval and consumption. In addition to this they also increase the footprint associated with the coil storage.

The second major challenge is the large occurrence of double-handling. When a pick is to be performed the current physical layout results in the need of having to move other coils back and forth to retrieve the one that is requested. The double-handling also occurs because of the storage being both with and without pallets, resulting in palletizing and depalletizing coils moving through the PA. Finally, the double-handling is also related to the unnecessary touch points which increase the number of times a coil is moved.

The third major challenge is related to the late quality check which results in a risk of storing coils with quality deviations. Since many coils are not frequently picked it also complicates the quality-claim processes. In addition to this, the late quality check also increases the picking times. With the quality check including depalletizing, unpackaging, and inspecting the coil, the picking time is substantially increased. All of the challenges described are not in line with Alfa Laval's goals of space utilization and handling efficiency, and changes to these challenges would have a great impact in achieving these goals. A summary of the challenges and their respective sub-challenges can be viewed in Table 5.7 below.

Table 5.7 - Summary of the most impactful challenges with the current warehouse configuration

Major challenges	**Sub-challenges**
Unnecessary touchpoints	• Unnecessary touchpoints because of the transportation in- and out-door • Low space utilization • High risk of obsolete coils because of dirt • Need of different trucks for transportation in different locations.
Double-handling	• Coil to be picked often require double-handling • De-palletizing coils • Storage on pallets • Double-handling because of up to 6 coil deep lanes.
Late quality check	• Quality checking each new coil during picks • Late quality checks

6. RECOMMENDATIONS

The aim of this chapter is to finalize the purpose of the report by proposing two recommendations of a new warehouse design. The design frameworks presented in chapter 3.5 have been used as a guideline during the project to support the purpose of designing a new warehouse. As an example, the first step “Define system requirements” were addressed in the delimitation of chapter 1 as well as when discovering the goals in chapter 4. Following this, the second step “Define and obtain data” and the third step “Analyze data” were covered in chapter 4 and 5 respectively. For this chapter, later stages of the framework will be covered. As a summary, first the recommendation on operational procedures and methods are presented which is then followed by the design and resources. The design proposal is made with theory foundation, the challenges experienced with the current design, the contextual factors, as well as the company goals for the new design in mind. As a concluding remark the recommendations are evaluated and compared with each other.

6.1 Warehouse operations

In the analysis of the current operations in the previous chapter, many challenges with the current setup were identified. To be able to address these challenges a new operations setup is recommended, see Figure 6.1. The first step of the processes, that is within the scope of this thesis, is the receiving of the delivered coils in the warehouse after they have been unloaded by the yard staff. This part should still include a control of the order number and weight, as well as a visual inspection of the coil. The coil should also be given a label and a barcode so that it can be entered in the information system. In addition to this, the coil should be unpacked and removed from the pallet. This will include a complete inspection of the coil including its quality and measurements.

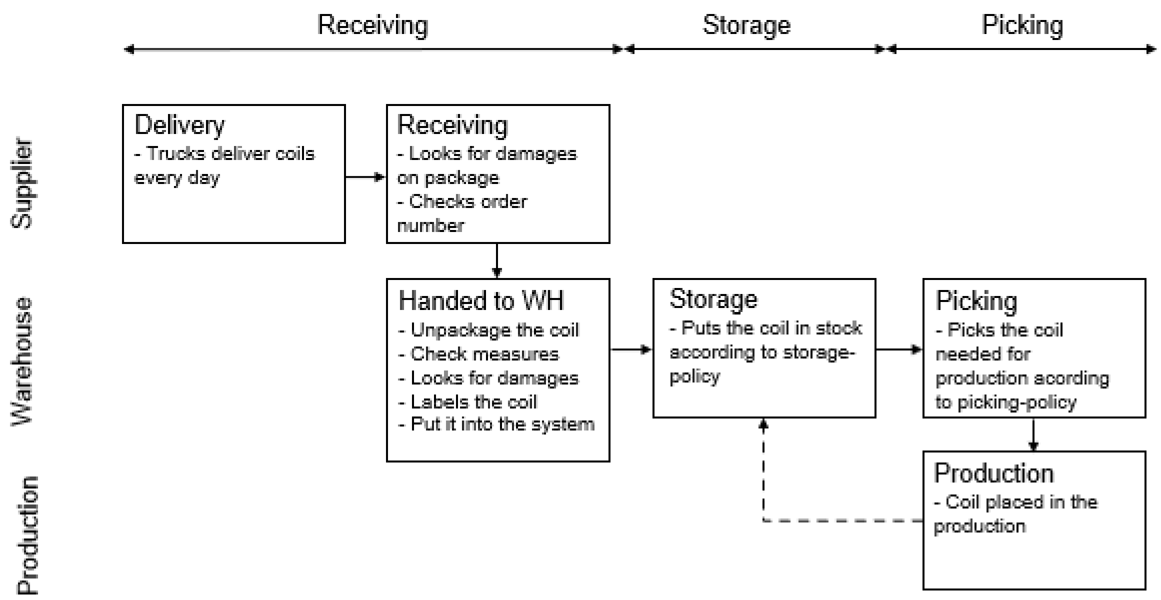

Figure 6.1 - The new flow chart where the dashed line is restorage of coils if needed

The next step in the operations is the storage. One change of this process is that the coil is now stored without a pallet to facilitate the handling. Instead of the former random storage policy, the coil is put-away by a class-based storage policy. The policy should be based partly on the popularity of the coil, so that frequent coils are placed in the convenient locations of the warehouse, and the product characteristics of the coils, to match the coil with the storage equipment characteristics which could be to store the heaviest coils in cradles.

For the picking process, further emphasis is put to pick the correct coil. Instead of only being told which article to pick, the information system should tell which specific coil that should be picked for the production. The major change of this process is the elimination of the additional activities that were performed both at the PA and coil stock area. Instead of taking the coil through a number of different steps, the picking is simplified to take the coil directly from the warehouse, with the beam truck, to the production machine. In the same way, returning coils are taken directly from the production machine back to the warehouse, without any intermediate steps. Because of the product characteristics, the picking strategy and policy is left unchanged. See Table 6.1 for an overview of the storage and picking configuration.

Table 6.1 - Decisions suitable for the case company within warehouse operations

Configuration area	**Sub-area**	**Reason**
Storage policy	Class based	Suitable for large differences in coil popularity
Picking strategy	Serial	Only one warehouse worker
Picking policy	Single order	Product characteristics

6.2 Warehouse design and resources

This subchapter will present a summary of the physical layouts, the information system, and the equipment for the two recommendations. The recommendations are based on the analysis in the previous chapter of how changes of the configuration elements can address the identified challenges and goals of the new design. Firstly, a general recommendation will be given on which changes should be done to the design and resources without going into specific storage equipment or layouts. This is because the two recommendations have differences in those areas, which will be presented in subchapters 6.2.1 and 6.2.2.

When the different layouts were produced, they were highly dependent on the storage and picking equipment that were going to be used. But the overall targets of the different configurational elements would still be the same. These targets are presented in Table 6.2 and consist of the main areas of physical layout, equipment, and information system. The physical layout should be long and narrow, using the height and lowering the number of aisles to increase the volume utilization, and have a U-flow to decrease the picking time. The equipment which both of the recommendations have is a truck equipped with a boom to transport the coils from the receiving area to the storage and from the storage to the production and the coil turner. The information system which both of the recommendations have is a new WMS which is equipped with the storage and picking policy to allocate the coils according to popularity and increases the correct picks, support of the barcode system to trace the coils, and support the master data with the right information of the inventory.

Table 6.2 - Configuration decision of information system and equipment

Configural element	**Sub-area**	**Suggestion**	**Reason**
Physical Layout	Footprint of the building	Long and narrow building	In line with goal of high space utilization
	Space utilization	Rack storage / Using height	Increase volume utilization
		Multi-deep storage	Increase space utilization with deeper lanes
	Flow configuration	U-flow	In line with low volume characteristics and high popularity distribution
	Aisle configuration	Few parallel aisles without any cross-aisles	To maximize the space utilization
Equipment	Storage equipment #1	Cantilever racks	Uniformly stores all coils with all dimensions and increases space utilization
	Storage equipment #2	Overhead crane with stacking floor storage	Higher safety, less errors, and increased space utilization without aisles
	Handling equipment	Truck with boom attachment	Supports the coils without pallets
		Coil turner	To raise the coils laying down
Information system	WMS	Storage and picking policy	Proper allocation according to popularity distribution and increases the number of correct picks
		Barcode support	Support tracking of storage locations
		Master data	Support better analysis and use of KPI with correct data

6.2.1 Cantilever

The first recommendation is to use cantilever storage racks where the coils are stored without pallets and the handling is done manually with a truck equipped with a boom attachment. An example of these racks can be seen in Appendix D and the recommended layout is demonstrated in Figure 6.2. The configuration consists of four aisles which is a trade-off between minimizing the footprint and having an adequate receiving area to handle peaks, while still ensuring feasible dimensions of the building. The aisles are oriented parallel to the flow with a U-flow configuration in accordance with the popularity distribution. To utilize the height the racks are four levels high, where the first level consists of cradles on the ground and the rest are cantilever arms.

The solution has two possibilities of capacity with the suggested layout that are dependent on which lane depth that is used. With each cantilever being 800 mm, the maximum feasible lane depth is determined by the coil widths stored on each arm. The first setup is that single-deep storage is used where each arm or cradle stores only one coil, no matter the width. This makes all the coils accessible which reduces the double-handling but with the downside of lower space utilization. The other setup is that multi-deep storage is used where only the same type of article is stored on each arm or cradle. This increases the space utilization but decreases the accessibility of the coils. Both these types use the same number of cantilevers and cradles and have the same footprint.

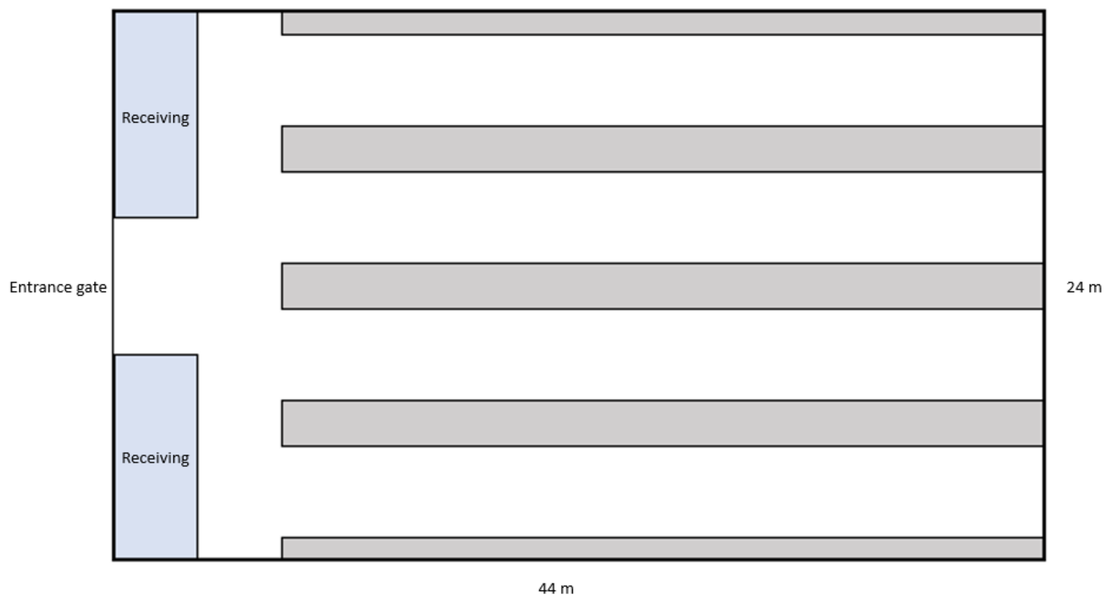

Figure 6.2 - Layout configuration of the cantilever storage warehouse

The suggested layout consists of 800 arms or cradles which correspond to either 800 or 950 storage locations depending on if a single or multi-deep setup is used. The total footprint is 1,050 m^2 out of which 75 m^2 is reserved for the receiving of new coils. The layout is accompanied by data regarding footprints and capacities in Table 6.3 below.

Table 6.3 - Footprint and capacity of the suggested layout

Overall footprint	1,050 m^2
Receiving area	75 m^2
Storage locations	950 coils

6.2.2 Overhead crane

The second recommendation is an automated overhead crane solution. The interface between the employee and the automated solution is an input and output zone where the coils are placed for either put-away or retrieved for picking. An example of how this solution can look is seen in Appendix E and the recommended layout is seen in Figure 6.3. The space utilization is increased by removing all of the aisles between the stored coils since they now are picked with an overhead crane. The only space needed between the coils is 300 mm between the bobbin of the coil where they are picked with the crane and 150 mm in the other direction. The coils are stored on the ground, standing up, where the coils with a width of at least 625 mm are stacked on top of each other, two levels high. The rest of the coils are stored without stacking because of the tipping hazard, either with or without additional support. Because of the few stackable coils due to the product characteristics, the height utilization will be lower. Since this solution is fully automated from the input/output-zone the storage area is enclosed to ensure the safety of the employees by preventing access to the operating area.

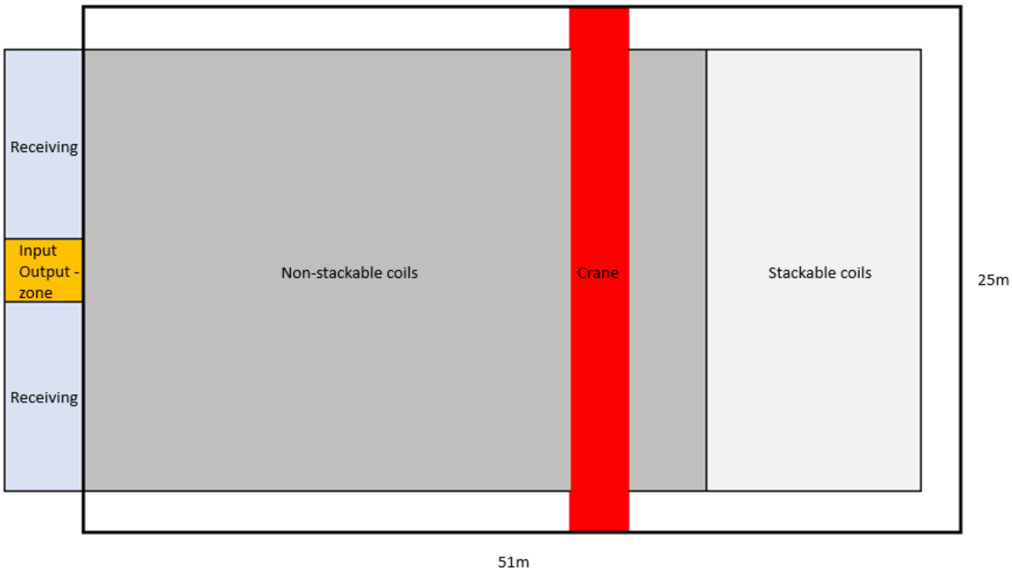

Figure 6.3 - Layout configuration of the overhead crane storage warehouse

The suggested layout will result in 950 storage locations with a total footprint of 1,400 m^2. Out of this there is 75 m^2 reserved for the receiving of new coils. The layout is accompanied by data regarding footprints and capacities in Table 6.4 below.

Table 6.4 - Footprint and capacity of the suggested layout

Overall footprint	1,400 m^2
Receiving area	75 m^2
Storage locations	950 coils

6.3 Comparison

6.3.1 Differences

Space utilization

These recommendations have their own advantages and disadvantages and to understand the situation they will be compared with each other. The first and major difference between the two solutions is the needed storage area to store the same number of coils. The recommendations include two different scenarios, with a maximum of 800 or 950 coils, which are then evaluated to a yearly growth of 5 %. This is based on the assumption that the coils currently stored are correct in both type and quantity and that the number of coils in stock increases, even though that might not be the case. Table 6.5 shows the footprint of the different solutions of 800 or 950 coils depending on whether single- or multi-deep storage is used. To compare these two scenarios with the overhead crane there are two different footprints which correspond to the same number of coils. As a side note, to store the current number of coils, 630, the single deep cantilever and overhead crane requires 770 m^2 and 975 m^2 respectively. This can be compared to the current footprint of approximately 2000 m^2.

Table 6.5 - Footprint of the different recommendations

Type	**Footprint**	**Coils**	**Time until full**
Cantilever (single)	1,050 m2	800	5 years
Cantilever (multiple)	1,050 m2	950	8.5 years
Crane #1	1,200 m2	800	5 years
Crane #2	1,400 m2	950	8.5 years

The difference in footprint is between the 800 coil solutions equal to just over 14 % where the overhead crane has the larger footprint. This speaks for the cantilever crane solution since the main goal of the new warehouse was to decrease the area of storage. This difference becomes even greater when it comes to the usage of more than one coil per cantilever arm, just over 33 %. The growth of the number of coils and time limits when these solutions reach the storage limit can be seen in Figure 6.4.

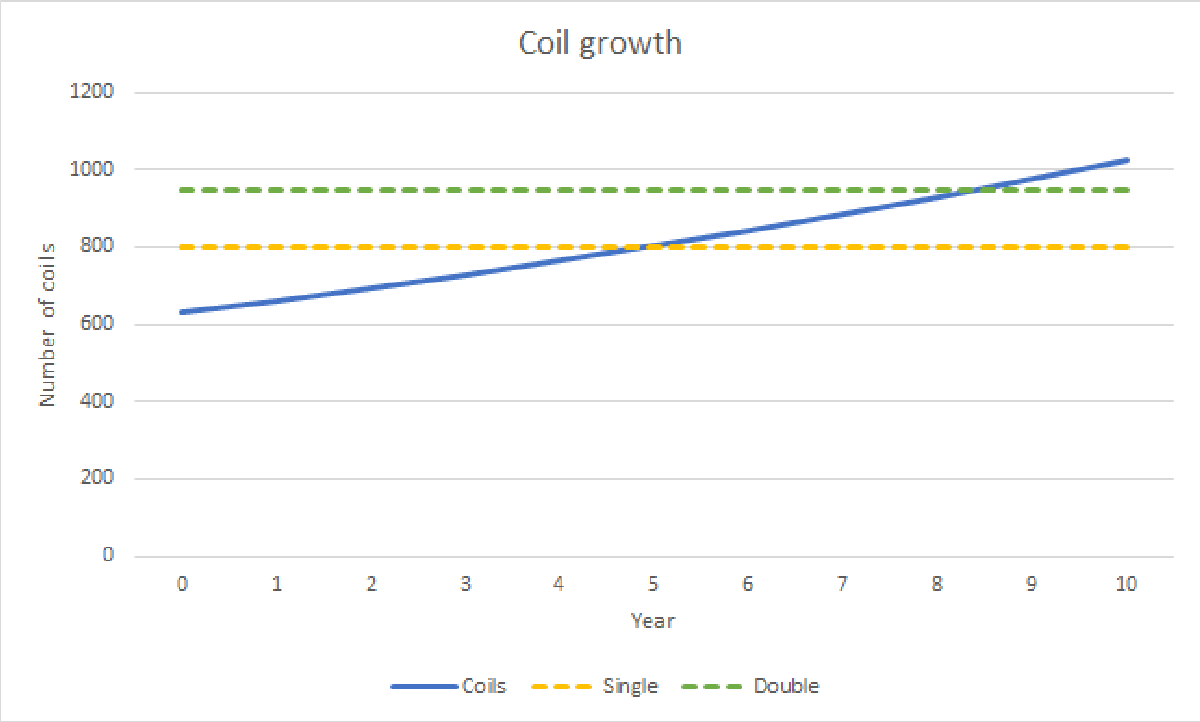

Figure 6.4 - Comparison of the storage solutions where the blue line is the coil growth, the yellow is 800 coils in stock, and the green is 950 coils in stock

Growth sensitivity

The growth of the number of coils that need to be stored in the warehouse could in the future be larger than the capacity resulting in the need of expansion. The cantilever solution is bought in sections where the customer can buy as many cantilever arms as needed. This will make it easier to buy more in a later stage and add them to the current setup. When it comes to the overhead crane solution the expansion is a much more difficult problem. Since the whole solution is to have a large crane on poles that can reach the whole storage area, the area of the warehouse is determined when it is built. Because of this risk with the overhead crane solution the footprint will probably be a bit larger to avoid this scenario if possible. The cantilever solution is more adaptable to increase the number of coils in stock, but also decreases in the number of coils where it is possible to remove cantilevers to reduce the needed space.

Picking speed

Decreasing the picking speed was the second goal of the new design of the warehouse. Since the time it took with the current setup was 25-30 min and included unpacking the coils, checking them for damages, and driving long distances with different trucks, this time would easily be decreased. But when it comes to the difference between the two recommendations in picking time, the difference should be negligible compared to the time saved. The cantilever solution includes the time to find the coil, pick it, and then drive back to the production while the overhead crane only includes the time to pick the coil from the output zone and drive straight to the production. How long it takes for each of these picks is difficult to estimate but the decrease from the current situation is significant, while the pick with the overhead crane solution is slightly quicker. However, the picking time is more important to lower in an accuracy of seconds if there are hundreds, or even thousands, of picks per day. This is not the case in this situation, with less than 20 picks on average, and the difference between the picking time of the two recommendations should not have a high impact when it comes to which one to choose.

Automation

One large difference between the two recommendations is that one of them is automated and that the other is not. This has an impact on the challenge and goal of having a high quality of the coils stored in the warehouse, as well as the goal of increased safety. Both of the solutions will have a decrease in the number of wrong picks because of the implementation of a WMS where the system tells the picker more exactly which coil to pick. But the automated overhead crane eliminates the risk that it still is the wrong coil that is picked, with the assumption that all the coils are labeled correctly. This automated picking process also decreases the risk of damaging the coils when they are picked. The only transportation is from the out-put area to the production instead of also needing to transport the coil manually in narrow aisles with the cantilever solution.

The current inventory suits an automated solution because of the uniform shapes of the coils. But automated solutions are more sensitive to changes in what the inventory consists of, such as different widths and diameters, which could result in problems of introducing new coils which the cantilever solution is less sensitive to.

Risk of disruptions

The risk of disruptions and the impact they have is important to take into consideration before deciding which recommendation to proceed with. If an equipment malfunction occurs the impact is significantly different between the two solutions. With the cantilever it would mean that the truck breaks. This could imply a stop in one aisle, but all of the other aisles would still be open, and the operations could proceed, if there is another truck to use. If the overhead crane would break, the result would be that the whole picking process and production stops. The result would be the same if the equipment needs maintenance, except that all the aisles would be accessible in the cantilever case.

Price

The price of the different solutions has been estimated through contact with one supplier of each equipment solution where the number of coils gave an indication of the needed size. As can be seen in Table 6.6 the price of an automated overhead crane solution is double the price of the cantilever solution. These prices include the storage equipment as well as the WMS needed to control the inventory, but not the facility needed for the different solutions.

Table 6.6 - Cost comparison

Solution	Cost approximation
Cantilever + WMS	6,000,000 SEK
Automated Overhead crane + WMS	12,000,000 SEK

Safety

There are many factors that speak in favor of the cantilever solution but one factor that could outweigh the other is the safety of the employees at the warehouse. The cantilever solution has employees handling the coils by truck when they put them in the storage, where the highest place is around 6 m above the ground. Because of the heavy coils the damage can be devastating if something goes wrong in that circumstance. To decrease the height the cantilevers can use three levels high racks instead but that increases the footprint by 25 %, which still is lower than the overhead crane when the coils are stored multiple deep. This results in a new difference in footprint of just below 8 % between the recommendations but the manual handling would still exist, though with a smaller risk since the height is lowered. The overhead crane on the other hand removes the need of handling the coils above the employee. The only contact the employee has with the coil is the transportation to and from the input and output zone which is handled at a ground level.

6.3.2 Summary of the recommendations

When it comes to the decision on which of these recommendations to proceed with, one has to see which trade-offs there are. The cantilever solution has a higher space utilization, is cheaper to install, is more flexible when it comes to the needed storage space, has a lower risk of disrupting the production if something happens, and is more likely to handle introduction of new coils better than the overhead crane. The cantilever will also be a smaller step in the development of the warehouse which lowers the effort needed and increases the chance of succeeding with the implementation. On the other hand, the overhead crane increases the safety of the operations, lowers the risk of damaging the coils which increases the quality, and lowers the risk that it is the wrong coil picked for production. In addition to this, space utilization is also a great improvement in comparison with the current situation. However, to achieve this impact there is a greater effort needed because of the large difference in development between the current setup and the overhead crane. To conclude, the cantilever recommendation has a good impact and requires less effort while the overhead crane recommendation requires more effort but has a greater impact.

Despite which recommendation that is chosen they will still reduce the same challenges that were discovered, which can be seen in Table 6.7. They do address them in different ways and to different extents, but they do both make a large difference compared to the current setup.

Table 6.7 - The identified challenges and if they are addressed by the recommendations or not

Configural element	Challenges	How they are addressed
Inbound operations	Small receiving area	Increased size
	Re-storage of coils require repackaging	The coils are stored indoors which removes the need of repackaging
Outbound operations	Quality checking each new coil during picks	Quality check and unpacking is performed pre- put-away
	Picking errors	Implement a WMS with picking policy
	De-palletizing coils	Coils are stored without pallets
	Coil to be picked often require double handling	Better accessibility
Physical layout	Double-handling because of up to 6 coil deep lanes.	Better accessibility
	Unnecessary touchpoints because of the transportation in- and out-door	Quality check and unpacking is performed pre- put-away, and all coils are stored together indoors
	The current setup with lanes does not facilitate using the FIFO method which is in use	Better accessibility
	Low space utilization	Utilizing the height and less aisles
	High risk of obsolete coils because of dirt	Indoor storage
	Small receiving area	Increased size
	Unfavorable storage conditions	Indoor storage
Operations strategy	Lack of storage policy	Implement a WMS
	Late quality check	Quality check and unpacking is performed pre- put-away

	Lack of documentation of lost coils because of the reliability on the inventory control	
	High stock levels of certain coils	
	Lack of follow-up on KPIs	
Warehouse equipment	Need of different trucks for transportation in different locations.	Indoor storage, and coils are stored without pallets
	Storage on pallets	Coils are stored without pallets
Information systems	Lack of traceability of the coils	Implement a WMS
	Lack of information of the order specific coils in the system	Implement a WMS
	No support for storage or picking policy	Implement a WMS
Labor	Scanning errors when coil is moved	Better accessibility, and clearer policies
	Does not always search for coils that are placed incorrectly	
	No documentation on coils that do not exist	
	Lack of commitment to FIFO	Better accessibility, and clearer policies
	Lack of competences, e.g., crane license	

7. CONCLUSION AND FUTURE RESEARCH

The aim of this chapter is to summarize the result of the thesis. This will include a brief description of the purpose, objectives, and an overview of the recommendations. Interesting areas that were identified during the progress of the project which are suitable for further research are presented to indicate the next steps in the process. The limitations of the project will also be discussed to highlight the reliability of the thesis. Lastly, the chapter will end with the authors concluding thoughts of the project.

7.1 Fulfilling the purpose

The purpose of the thesis was to provide Alfa Laval with two recommendations of how the production warehouse of coils could be designed to increase space utilization and make the handling process more efficient. To fulfill this, a description of the current warehouse situation was performed to understand the requirements of handling the coils and to identify the challenges with the current configuration. In addition to this, the contextual factors and how they affect the warehouse configuration was identified. All of this was done through interviews, observations, and data retrieval from information systems. The collected data was then analyzed through a framework which narrowed down the configural elements to the context of Alfa Laval. From this it was then possible to construct two holistic warehouse configurations that were adjusted to the context, addressed the challenges, and achieved the goals of the new design.

The recommendations included changes to the order of operations, with the quality inspection being performed before the put-away, and the removal of intermediate touchpoints. This reduced the picking time by a substantial amount which was one of the goals of the new design. The storage was also modified to store the coils uniformly without pallets during all steps. This made the handling process more efficient by reducing the double-handling associated with depalletizing and repackaging the coils. The design and resources were changed to new equipment and layout which utilized the space of the warehouse better. The recommendations either included cantilever rack or overhead crane storage. A WMS was also recommended to make processes more rigid by having set decision policies instead of random decision making and to increase the traceability and accessibility of the coils.

7.2 Addressing objectives

The objectives of this report were (i) Describe the current warehouse configuration, (ii) Identify the challenges with storage of coils, (iii) Identify the contextual factors for Alfa Laval, and (iv) Identify suitable configural elements in this context. A holistic summary of the most important findings is presented below. For further details the reader is referred to the other chapters.

Through the description of the current situation the challenges and contextual factors could be identified. The challenges were used to know what the new solutions were supposed to avoid or reduce while the contextual factors provided a framework on what the new solution had to adapt to. Some of the more important challenges identified were the long picking time that was based on the late quality check and that there were many unnecessary touchpoints in the chain. The long picking time was also connected to the need of changing trucks because of the transport being done both outdoors and indoors, as well as with different handling units. The late quality check also increased the risk of handling coils with quality deviations which resulted in unnecessary handling and storage of coils that would be sent back to the manufacturer in a later stage. This in turn increased the risk of not meeting the deadline from the customer because of the long lead time of a new coil delivery. Another challenge was the double-handling which was a result of the combination of storing the coils on the floor in up to six coils deep lanes and that the picking policy was FIFO. This meant that the coil further in usually was the one to be picked and resulted in the need of moving all the coils in front of it. This floor storage and the lack of adequate equipment resulted in a low space utilization.

The contextual factors that affected the possible recommendations the most were the product characteristics and the customer characteristics. The product characteristics had a large impact on how the picking could be done and which storage methods were applicable to the situation. Because of the size of the coils only one coil could be picked each time and the storage had to support the tipping hazard of the coils. The coil dimensions also had a significant impact on which storage equipment that was suitable. With regard to customer characteristics, certain customers have a high demand on traceability of the coil all the way from the production of the material to the finished product. This, in combination with the customers with nuclear heat exchangers, resulted in the need of high traceability and quality of the operations and storage.

With the findings of challenges and contextual factors of the current situation the configurational elements that would be combined into recommendations were determined. The operations should be using a class-based storage policy, in accordance with the popularity distribution, and the picking should be conducted in serial by a single worker because of the volume and product characteristics. The physical layout should better utilize the space by adjusting the aisle space, lane depth, and height used. The flow configuration should be a U-flow to further align with the popularity distribution and volume characteristics. Finally, a WMS should support functions related to the storage and picking policies, multi-depth storage, and master data.

7.3 Next steps for Alfa Laval

Throughout the thesis the recommendations were continuously presented and discussed with Alfa Laval. This helped ensure that the expectations of the output were met and that the recommendations were feasible in reality. During these meetings it seemed as if the overhead crane solution was favored by the office workers who thought that the cantilever storage rack would be difficult to operate. The warehouse team leader however favored the cantilever and did not think that would be an issue. In addition to deciding on which recommendation to choose, there are also other areas that need further investigation before the implementation can start. These areas are the inventory level, which KPI values to proceed with, and how the implementation should be done.

The first area to investigate is the inventory level of the warehouse. When generating the recommendations, assumptions were made that the current inventory level was correct. The recommendations should be seen as a concept of how the operations should be conducted and the resources configured, rather than a fixed configuration in absolute numbers. This is because the analysis of the data showed that the selected safety stock levels and re-ordering points were not in line with reality. Instead, many coils fluctuated either significantly below or above the decided stock level. In addition to this, it was also seen that certain coils were ordered for a specific project and if the project was cancelled no action was taken for these coils which stayed in stock. Therefore, in addition to deciding on which recommendation to proceed with, a detailed analysis of the inventory level of the warehouse should be conducted so that the scale of the design can be adjusted to the actual need.

The second area to investigate is which KPIs the new warehouse should work with. The previous KPIs were not used because of the untrustworthy data they were based on. The implementation of a WMS will make it possible to have the KPIs based on trustworthy information which makes them more usable. But, with the large changes in the operation and how the coils are stored the current KPIs should be updated or adapted to the new situation. Which specific KPIs that should be implemented is something excluded from this thesis and is instead an area for further investigation.

Finally, the natural step after deciding on the new warehouse configuration and required inventory level is to investigate how it should be implemented. With the recommendations of the new design being a significant change, especially in comparison to the current configuration, this is something that should be carefully considered. While the cantilever solution would be possible to implement step by step or as a pilot project, the overhead crane solution is less suitable for that and therefore more sensitive to the implementation.

7.4 Limitations

This thesis was limited by being a single case study where only one company was investigated. Because of this, it was difficult to generalize the output of the project and contribute to the theory. Another limitation of this thesis was the short time frame of 20 weeks. This narrowed down the scope of both the project and the output. Both of the recommendations were compared with each other, including a brief approximation of the costs. However, no detailed cost analysis of the recommendations was included which would have benefited the output of the project. A more detailed configuration proposal, such as detailed specification of the WMS, and a more iterative process of fine-tuning the configuration on a detailed level is also something that would have benefited the output of the project.

In addition to the limitations above, the automation chapter presented in theory also serves as a limitation to the project. The automation assessment tool was deemed as a valuable tool of suggested suitable automation levels for the warehouse. However, the references used can be questioned because of their date, which is especially true with regards to automation which is a fast-paced area of development. If newer sources would have been used the credibility of the report would have increased, but on the other hand the impact on the report is small when the complexity of the warehouse is taken into consideration.

7.5 Contributions

The project contributed to practice by solving challenges for Alfa Laval by suggesting two recommendations on new warehouse configuration. These recommendations improved the space utilization and handling efficiency of the warehouse. In addition to this, the thesis also contributed to the academic sector by adding an article within production warehouse design, which of the author's knowledge was an area covered scarcely. Many of the existing articles instead covered the designing of distribution warehouses.

The thesis did not discover anything new theory wise, but instead confirmed the importance of taking contextual factors into account when designing a new warehouse. The thesis also confirmed literatures view of warehouses not having been in focus of companies’ development for a long time. As a result of the report, it was discovered that the inventory level update could be suitable as a new master’s thesis subject at Alfa Laval. This would consist of determining the suitable number of coils in stock, the safety level, and the ordering frequency.

7.6 Concluding remarks

During the second half of the thesis the majority of the time was spent working at the case company. This increased the quality of the work by enabling both frequent discussions in person with employees regarding small questions of the project as well as unscheduled observations of the warehouse. By being on site the project also felt more realistic and made a great contribution to how enjoyable the thesis was experienced. Working remotely would both have hindered spontaneous discussions and observations as well as made the experience less enjoyable. In spite of the covid situation, the thesis was perceived as an enjoyable finish to our education.

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APPENDIX A - Interview guide

About us:

We are students at LTH that are performing a master thesis at Alfa Laval as a final project to complete our studies. The project has the objective of designing a new warehouse solution for the storage of coils. The main aim of the thesis is to improve space and labor efficiency. For doing this we are collecting secondary data through systems as well as conducting interviews with persons with various positions. Because of the general interview guide that will be used for several interviews, some questions may be more aimed towards you while others may be less fitting. The interview will be divided into four parts, introducing questions, warehouse operations (covering from put-away to shipping), design & resources (regards to current layout and equipment used etc.), and strategic questions regarding the warehouse strategy and contextual factors.

Introducing/general questions

Please describe your role at Alfa Laval.

What are your typical daily tasks?

What is the vision of the warehouse change for you?

Please describe the arriving flow of goods. How many different suppliers do you use? What does the replenishment look like (frequency and size etc.)? In what handling unit does the coil arrive? Are they checked for quality deviations?

What is the outlook for the introduction of new products in the warehouse?

Warehouse operations

Put-away

Please describe the procedure for a put-away of arrived loads of coils. (Are they scanned to transfer locations?)

How often do shipments of coils arrive?

How time consuming would you rate this task? (Average time per put-away)

Are there any coils that need special handling? How are they handled?

What are the challenges with this process?

What would you want to change if you had the possibility?

Is there anything that you would like to keep as it is?

Storage

What is the current storage policy? How is the location of a coil decided?

How do you treat different coils?

How do you track the location of a coil?

What is the current situation of capacity?

What is the expected growth trend?

How many coils do you store in total, what level of variety is there?

What are the challenges with this process?

What would you change if you had the possibility?

Is there anything that you would like to keep as it is?

Picking

Please describe the process of picking coils in the warehouse.

How do you retrieve your orders and how are they transformed to pick lists?

What is the current picking policy? (Batching, zoning, one picker per order etc)

How time consuming would you rate this task? (Average time per pick)

What are the challenges with this process?

What would you change if you had the possibility?

Is there anything that you would like to keep as it is?

Warehouse design & resources

Layout

What is the current warehouse layout?

What is the reason for this layout?

What are the issues with this layout? (Congestions?)

What is your view on what should be changed?

How do you think about safety requirements? (Storing coils high)

Is there anything that you would like to keep as it is?

Equipment

What equipment do you use and in what number? (Racks and trucks)

Are there any issues with any of the equipment types? What would you like to have as well/instead?

Automation

What is your opinion of automated storage?

Is there any automation or other kind of technology in use in the warehouse or any other part of the factory?

What does it do?

Information system

Do you have any information systems connected to the warehouse?

Are there any plans on changing the system, upgrading it, or extending the existing contract?

Are there any gaps in the information system setup? (Functions that are missing)

Labor and other activities

How many warehouse workers are there currently working with the coil storage? Do you have extra workers to cope with seasonality?

Do you hire an external labor work force or is it only inhouse labor?

How do they work? (Shifts, hours)

Strategic questions

Strategy

What is the current strategy of the supply chain?

What is the goal going forward for the strategy? Will it change?

Goals

What are the goals of the new warehouse? (Space utilization, flexibility, etc.)

What is the time expectancy of the new warehouse? (Time horizon)

What is your view on what should be changed?

How do you think about safety requirements (storing coils high)

Is there anything that you would like to keep as it is?

Contextual factors

What factors exist that affect the current operations and configuration of the storage of coils.

Are there any special overall requirements for handling and storing the coils you do? (Regulations, laws, temperature)

Other questions

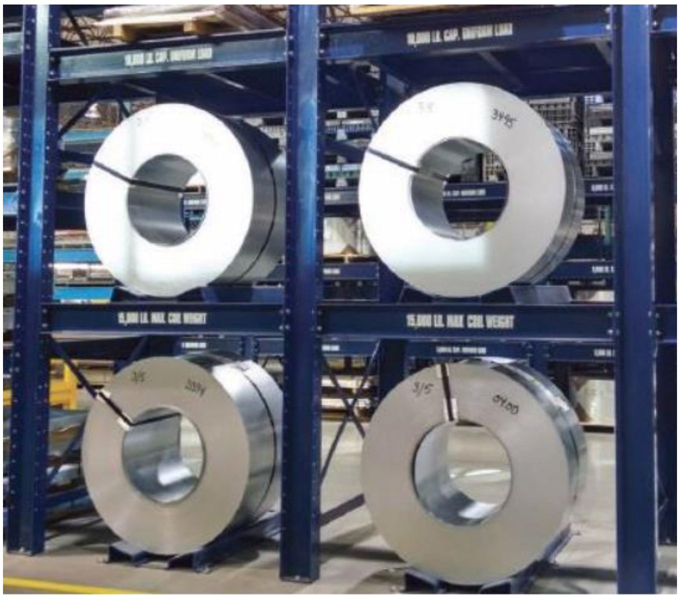
From our knowledge, the coils that are stored in the yard are sometimes not opened until long after their delivery, meaning that it is too late to request refunds if they are deemed incorrect/damaged. How often would you estimate that this occurs?

Do you have any KPIs you work with? If so, which ones?

How do you follow up KPIs?

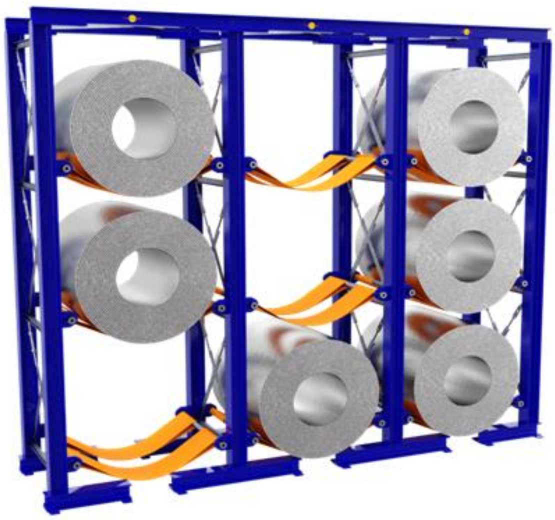
As a final question, is there anything not covered that you would like to discuss?

APPENDIX B - Coil rack



Coil rack storage, (Warehouse Rack and Shelf, 2021)

APPENDIX C - CoilStore rack



CoilStore rack storage, (Hoppe, 2021)

APPENDIX D - Cantilever rack

Cantilever rack, (OHRA GmbH, 2021)

APPENDIX E - Overhead crane

Overhead crane, (Demagcranes, 2021)