Developing a Warehouse Layout Design Framework for Fast Growing Companies

A Case Study at Oatly AB

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Abstract

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Problem description: The importance of the warehouse in the supply chain network is increasing and the overall efficiency of a supply chain is to a large extent determined in the warehouses. It is acknowledged that warehouse design is a complex task mainly due to the many relationships to other functions within the company. The complexity is further enhanced by many activities and parallel processes performed within the warehouse. As a consequence, there are many aspects needed to be considered when developing a warehouse layout. Warehouses are generally expensive to change regarding facility, equipment and racks. Companies in volatile and fast moving markets should therefore consider the future demand and flexibility to changes in future demand in the warehouse layout design process.

Purpose: The purpose of the study is to develop an aligned warehouse design solution for current and future operations considering a company´s growth expectation.

Research questions: What aspects should be considered when designing a warehouse layout to ensure that it is aligned with the company´s growth expectations? How can a warehouse layout design be generated that ensures flexibility and ability to handle future warehouse operations?

Methodology: To find a warehouse solution that is aligned with the current and future operations a warehouse the answer to the research questions was investigated in current research on warehouse layout design. The aspects found which were considered important for fast growing companies were thereafter put in a framework, the *warehouse layout design framework*. The framework has its basic structure from current literature on warehouse layout design. The framework has been applied through a single case study at Oatly AB. Oatly AB is suitable for this study as the company has experienced considerable growth during the last few years. Based on the case study, further refinements have been made to the framework.

Conclusion: Aspects that have been found to be especially important for the development of the warehouse layout are growth expectations, the current layout and flexibility for a volatile future demand. The objective of the warehouse, primarily the focus on product portfolio strategy, was also found to be an important aspect for the layout design. The warehouse layout design framework puts additional focus on the growth of the company and as a consequence, forecasting of the expected in- and outbound warehouse material flows. Therefore, the framework is useful for companies facing unsure growth. The main benefit of the framework is the sequence of steps that guide the user towards an aligned warehouse layout. The steps does not allow for any aspects being left out in the analysis. Additional case studies should be made to find other aspects being of high concern for other types of warehouses in different industries.

Keywords: Warehouse design, warehouse layout design, layout, flexibility, growth expectations, warehousing

Sammanfattning

Titel: Utveckling av ramverk för design av lagerlayout för snabbväxande företag – En fallstudie på Oatly AB

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Problembeskrivning: Stora delar av effektiviteten i en logistikkedja bestäms i lagren varför dess betydelse och ökar. Lager är komplexa att designa primärt på grund av dess komplicerade relation till andra funktioner inom företag. Komplexiteten ökar ytterligare genom mängden aktiviteter och parallella processer som pågår i lagret. Som följd finns det många aspekter som måste tas hänsyn till när en lagerlayout ska designas. Eftersom lagerlayouter generellt är dyra att ändra gällande fastigheter, inventarier och hyllsystem bör företag som befinner sig i föränderliga och osäkra marknader överväga den framtida efterfrågan noggrant. Genom noggrant övervägande och flexibilitet i lagerlayouten kan företag bedriva kostnadseffektiv lagerhantering i dessa marknader.

Syfte: Syftet med studien är att utveckla en lagerlayout som är i linje med ett företags nuvarande och framtida lagerverksamhet med hänsyn till företagets förväntade tillväxt.

Forskningsfrågor: Vilka aspekter bör övervägas vid design av lagerlayout för att säkerställa att designen är i linje med företagets förväntade tillväxt? Hur genereras en lagerlayout som säkerställer flexibilitet och förmåga att tillgodose framtida behov för lagerverksamheten?

Metod: För att designa en lagerlayout som är i linje med den nuvarande och framtida lagerverksamheten har ett ramverk för design av lagerlayout utvecklats. Ramverket har sin bas i nuvarande litteratur om lagerdesign och aspekter som påverkar växande företag. Ramverket säkerställer att inga aspekter blir förbisedda. Ramverket har blivit applicerat genom en casestudie på Oatly AB. Oatly AB är lämpat för studien då företaget under de senaste åren har upplevt stark tillväxt. Baserat på casestudien har ytterligare ändringar gjorts på ramverket.

Slutsats: Aspekter som har identifierats som viktiga för utvecklandet av lagerlayouter är den förväntade tillväxten, den nuvarande lagerlayouten och flexibilitet för framtida skillnader i efterfrågan i lagerlayouten. Utöver dessa aspekter har lagrets övergripande mål, där framförallt produktstrategi ingår, en stor roll i utformningen av lagrets layout. Ramverket för design av lagerlayout lägger stor vikt vid företagets tillväxt och genom det, prognoser för det förväntade in- och utflödet till och från lagret. Ramverket är därför är användbart för företag som upplever osäker framtida tillväxt. Den främsta fördelen med ramverket är ordningen i vilka stegen hjälper användaren mot en lagerlayout som är i linje med företagets verksamhet. Bredden i ramverket låter inte några aspekter bli förbisedda. För att öka användbarheten i ramverket bör ytterligare studier genomföras för att hitta aspekter som kan vara av stor vikt för andra lagertyper i andra branscher.

Nyckelord: Lagerdesign, design av lagerlayout, layout, flexibilitet, förväntad tillväxt, lagerhantering

Preface

This thesis has been written as the finale of the Master of Science in Industrial Engineering and Management specializing in Supply Chain Management at the Faculty of Engineering at Lund University. The project has been conducted with Lund University and with Oatly AB where a case study has been performed.

We would like to thank Sofia Lindgren at Oatly AB for initiating the project as well as providing us with useful advice and help throughout the project. Also a special thanks to our supervisor at Oatly AB, Magnus Olin, for the support, providing of information and for making us feel welcome during our visits to Landskrona. Last but not least, a great thank to our supervisor at LTH, Joakim Kembro, for valuable discussions and for challenging us throughout the project. Without your input the red thread might still be a bit tangled.

The finalization of this thesis marks the end of an era as five years of student life in Lund now lie behind us. We would like to dedicate a special thanks to our dear friends at the round table who made the long days of writing this thesis a delight. Of course a special thanks to our classmates, the students in the guild of Industrial Engineering and Management and all others who have made our five years in Lund remarkable and memorable.

Lastly, we would like to thank our families and better halves, Madelene Rundin and Axel Janson, for their unconditional support, thoughtful advice and encouraging optimism throughout these years.

The noblest pleasure is the joy of understanding
Leonardo da Vinci

Lund, June 2015

Felix Geuken and Louise Jäger

Structure of Thesis

The Introduction starts with a background and problem discussion which present the subject of the thesis, warehouse layout design, and its importance. Thereafter the purpose for the thesis and the two research questions are elaborated. Lastly the delimitations of the thesis are stated.

The Frame of Reference provides a theoretical background to warehouse design. A thorough literature review of warehousing and warehousing layout design is presented along with current theory regarding fast growing companies. Relevant aspects in warehouse layout design for fast growing companies are investigated and highlighted throughout the chapter.

The Methodology describes the methodological choices made throughout the thesis. The research strategy selected for this thesis is case study. The strategy choice is motivated and case study research is generally described. Thereafter the three parts of the research design are presented; the case at Oatly AB, data collection and data analysis plan. In the methodology chapter the warehouse layout design framework is presented. The data collection and analysis models suggested in the steps of the framework are described. Lastly the strategies of ensuring the research credibility are presented.

In Applying the Framework on the Oatly Case the developed framework is applied to the Oatly warehouse. The chapter is divided into sections for the eight steps of the warehouse layout design framework. Each step is concluded with a summary where the findings and outputs of the steps, and sometimes parts of steps, are presented.

Analysis of the Warehouse Layout Design Framework will provide a discussion regarding today's research in relation to the study and the purpose of the research. The analysis is divided into two steps. The first step analyzes and discusses reviewed theory on aspects in warehouse layout design and frameworks found in literature. The second step analyzes the usability of the developed framework. It also highlights the warehouse layout design framework's strengths and weaknesses.

Conclusions and Further Research starts with the conclusions of the two research questions presented in chapter 1. Further research which could be conducted to elaborate and strengthen the results of the study is suggested and discussed. The study's limitations due to the delimitations set in the thesis are identified and discussed.

Table of Contents

1. Introduction

1.1. Background and Problem Discussion

The importance of the warehouse in the supply chain network is increasing. A company's competitiveness is directly influenced by its ability to accomplish efficiency in terms of a high rate of zero-defect-on-time deliveries in their supply chain network (Frazelle, 2002). Supply chain efficiency is to a large extent determined in its nodes, the warehouses. In today's business climate there is a trend towards more product variety and shorter response times. This puts increasing pressure on warehouse performance in terms of storing articles and ability to assemble customer orders. (Rouwenhorst et al., 2000) The warehouse performance is largely determined during the design phase of the warehouse layout. (Rouwenhorst et al., 2000; Gu et al., 2010; Tompkins et al., 2010)

It is acknowledged that warehouse layout design is a highly complex task primarily because the warehouse performance affects, and is affected by, other functions within a company's ability to operate adequately as well as ensure the company's competitiveness. (Baker & Canessa, 2009; Roodbergen et al., 2014; Rouwenhorst et al., 2000) For this reason the warehouse services have many stakeholders. Additionally, it may be the only view that end customers have of the company's operational capabilities. (Roodbergen et al., 2014) Many aspects need to be considered when designing a warehouse both within the warehouse operations and the company's supply chain network as a whole. These aspects consider both the nature of the business in terms of customer requirements and demand patterns such as seasonality as well as the characteristics and requirements of the product. The degree of complexity of warehouse design is largely determined by the number of activities and parallel processes that are performed in the warehouse.

A warehouse design is fixed in nature as it is often expensive to change after implementation. Both due to high investment costs in new facilities, racks and equipment and due to opportunity costs for down time in operations. (Bartholdi & Hackman, 2014) A warehouse normally operates on an everyday basis. A redesign that requires shut down of departments in the warehouse is not an option for many companies (Gu et al., 2010). High costs derived from lost sales, use of a third party logistics (3PL) provider or lost production rate can cost more than the warehouse investment itself. For this reason it is important for companies that are acting in volatile or fast moving industries or for some other reason are expecting considerable changes in demand to consider flexibility in their design process. This is to ensure a successful warehouse design solution that is aligned with the company strategy for the life span of the investment. (Frazelle, 2002; Gu et al., 2010). The requirements and expectations on warehouses ability are changing. Tompkins et al. (2010) state that it is old fashioned to view warehousing as a non-value adding activity. Trends in supply chain management such as supply chain integration and supply chain postponement has led to that more value adding activities are performed within warehouses (Twede et al., 2000; Frazelle, 2002; Gu et al., 2010). Besides storing and distribution other activities such as repacking and final assembly of products has been introduced to the warehousing service portfolio.

To support the design process of warehouses, researchers have formed frameworks (Rouwenhorst et al., 2010; Hassan, 2002; Govindaraj et al., 2000; Bodner et al., 2002; Tompkins et al., 2010; Gu et al., 2010; Baker & Canessa, 2009; Roodbergen et al., 2014). Most frameworks reviewed are based on literature reviews and are yet to be tested in practice while others are developed with the help of experienced practitioners and relate loosely to academia. The availability of frameworks covering the whole design process, from purpose identification to evaluation, is limited in current research (Baker & Canessa, 2009; Rouwenhorst et al., 2000) and there is a need for further research that connects practice with theory (Baker, 2006; Rouwenhorst et al., 2000; Gu et al., 2010). Rouwenhorst et al. (2000) state that most of the articles available on warehouse design are limited to well-defined and isolated problems. However, problems related to warehouse layout design are seldom well-defined and cannot be reduced to multiple isolated sub-problems. This means that warehouse designer need a mixture of creativity and analytical skills to handle the complex interactions between warehouse activities, future demand and space requirements. (Ashayeri & Gelders, 1985)

1.2. Purpose and Research Questions

Designing a warehouse is an intricate process with many trade-off decisions to be made between conflicting objectives. The complexity of the process is further increased by the high number of feasible design solutions. (Rouwenhorst et al., 2000) A warehouse design is fixed in nature as the investment cost for redesign is considerable. To ensure satisfying warehousing performance during the life span of the warehouse it is important to take the corporate strategy and growth expectations into consideration during the design phase. (Roodbergen et al., 2014; Rouwenhorst et al. 2000; Gu et al., 2010) The purpose of the study is to develop an aligned warehouse design solution for current and future operations considering a company's growth expectations. The literature review made it evident that a method to generate a layout design that incorporates future operations in an adequate way is needed. The following research questions are investigated and answered in the thesis:

RQ1: What aspects should be considered when designing a warehouse layout to ensure that it is aligned with the company's growth expectations?

RQ2: How can a warehouse layout design be generated that ensures flexibility and ability to handle future warehouse operations?

The research questions answered in this thesis are visualized in figure 1.1. RQ 1 is answered through a literature review of current research on warehouse layout design and research connected to future operations of a company such as forecasting of demand. To answer RQ 2 the aspects found in RQ 1 were used to develop a framework, a warehouse layout design framework, with a structure based in frameworks found in current research. The warehouse layout design framework was thereafter further refined through an in-depth case study at Oatly AB. Oatly AB is a fast growing company suitable for the research questions due to its unsure future demand. Oatly AB's current warehouse solution is neither aligned with the company strategy nor the company's growth expectations for the time frame considered.

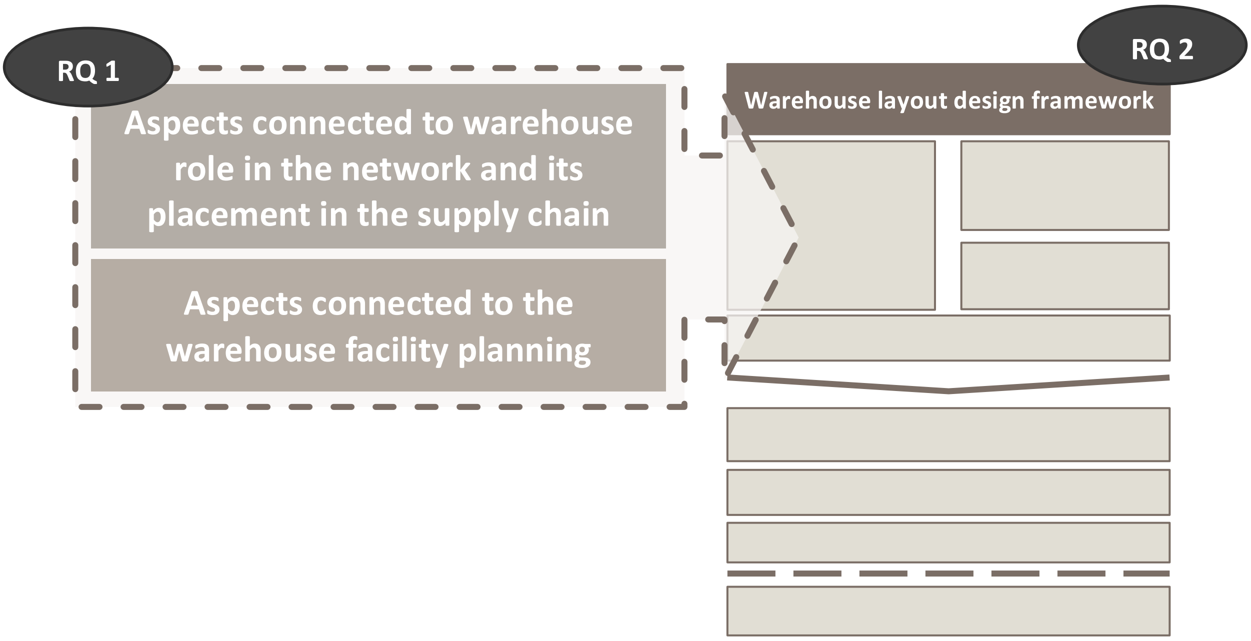


Figure 1.1. Aspects covered in this thesis (RQ1) connected to the warehouse layout design framework (RQ2).

1.3. Delimitations

The scope of this study is to investigate aspects that should be considered when designing a warehouse layout and how a layout design can be generated. This study is divided into two parts, starting in a review of existing theory about aspects to consider in warehouse design. These aspects are analyzed and put into a framework, warehouse layout design framework. The second part of the study is a single case study at Oatly where the warehouse layout design framework is refined through one practical application.

The aspects considered in the first part are limited to aspects that have a long-term (>10 years) effect on the company's requirements on the warehouse layout design. Operational aspects like work process design and scheduling of staff are not considered. The main objective of developing a new framework is to emphasize the future growth expectations of a company's effect on the layout designs need for flexibility. The project was limited to 20 weeks which has delimited the depth sought in the solution. The case study looks at a unit-load warehouse why the warehouse layout configurations and rack systems investigated in the frame of reference is aimed towards warehouses handling pallets.

The thesis will not aim to change any of the inputs to the developed framework, such as the corporate or supply chain strategy, material in- and outflow, product requirements or development of new rack designs. For this reason procedures in how to change these to enable better flows to the warehouse are not investigated. However, effects on the warehouse from changes in these flows have been investigated. The importance of forecasting expected demand on the warehouse is emphasized in the warehouse layout design framework. The study will highlight what in- and outflows are important to forecast to develop a comprehensive future scenario for the warehouse. This means that this study does not develop procedures to build scenarios to analyze future growth expectations in the case study, it will merely use forecasts provided in the case study in the generation of the solution. In the case study the space requirements for the activities as they are performed today as well as any potential additional activities are considered.

2. Frame of Reference

In the frame of reference focus is put on identification of important aspects to consider within warehouse design as well as on support to the development of the framework used in this study. The frame of reference is divided into two main parts, warehouse design aspects and warehouse design process as is visualized in figure 2.1. The warehouse design aspects consider the aspects in warehouse design that affect the warehouse structure. The supply chain strategy is considered to find the long term objective of the warehouse and to identify the economic life span that is suitable for the warehouse. The warehouse placement in the supply chain network and its effect on the warehouse material in- and outflow is elaborated. The storage handling unit affects the work processes and equipment selection in the warehouse.

The second part of the frame of reference is the warehouse design process and refers to aspects that are considered in direct relation to the facility planning of the warehouse both regarding facility size and interior design. Space requirements planning considers aspects such as growth expectations derived from the corporate strategy and forecasts, demand patterns and seasonality and allocation policies. The warehouse facility and the material handling processes within the warehouse are affected by the product requirements. The product requirements will set constraints on the storage environment and ability of the material handling equipment. The level of automation in the warehouse that is economically justifiable is to a large extent determined by the throughput in the warehouse and the cost of rent and labor in the area where the warehouse is located. Lastly the warehouse layout design decisions regarding aisle configurations and lane depth are elaborated.

Figure 2.1. Visual representation of the Frame of Reference

2.1. Warehouse Design Aspects

When designing a warehouse there are many aspects to consider. Design decisions are interconnected which leads to trade-off situations and reiterations in the design process. (Gu et al., 2010; Rouwenhorst et al., 2000; Baker & Canessa, 2009) The design aspects need to be considered to avoid sub-optimizations in the supply chain and consequently guide the warehouse designer in the trade-off situations that emerge in warehouse design. (Gu et al., 2010) Focus is in this section therefore on understanding the interactions within the supply chain and material flow through the warehouse and not on the specific design elements of warehouse design. A warehouse can play many roles in a supply chain. Three typical examples are production warehouses, distribution warehouses and contract warehouses. (van den Berg & Zijm, 1999) The warehouse type's effect on the warehouse design is elaborated in this section as well as the performance measurements that are commonly used as design criteria for the different warehouse types. The warehouse role and placement in the supply chain network affects the characteristics of the material flow to and from the warehouse. The warehouse design is affected by the storage handling units used in the warehouse in work process design, department allocation and in equipment selection. (Bartholdi & Hackman, 2014) Connected to the material flow are the space requirements. Therefore demand patterns, seasonality and growth expectations will be covered. (Frazelle, 2002; Rouwenhorst et al., 2000; Gu et al., 2010)

2.1.1. Supply Chain Strategy Influence on Warehouse Objective and Design

Tompkins et al. (2010, p. 292) state "A facilities layout strategy should emerge from the overall strategic plan". The focus on the corporate strategy is further supported by Rouwenhorst et al. (2000) who argue for the importance of the top-down approach in warehouse layout design to avoid a suboptimal final solution. Demand and supply characteristics affect the material flow in and out of the warehouse. These characteristics are largely determined by the warehouse placement in the supply chain network. (Lee, 2002; Frazelle, 2002) Fisher (1997) states that it is of key concern to understand the demands that the product puts on the supply chain and align the supply chain thereafter. In figure 2.2. a variant of the Fisher-matrix developed by Lee (2002) is shown. The figure has two axes; demand uncertainty and supply uncertainty. Depending on the combination of demand and supply uncertainty different types of supply chains are needed. For example companies with low demand uncertainties, with functional products, and low supply uncertainty, stable production, can benefit from an efficient supply chain.

		Demand uncertainty	
		Low (Functional products)	High (Innovative products)
Supply uncertainty	Low (Stable production)	Efficient supply chain	Responsive supply chains
	High (Evolving produciton)	Risk-hedging supply chains	Agile supply chains

Figure 2.2. Matching of supply and demand uncertainties and supply chain strategy. Based on Lee (2002).

To characterize the demand and supply there are number of parameters that can be taken into consideration when identifying the products and the production. The supply and demand characteristics are shown in table 2.1. as proposed by Lee (2002). In demand the low uncertainties come from functional products and high uncertainties from innovative products. Within supply the low uncertainties come from the stable supply and the high uncertainties from evolving production.

Table 2.1. Demand and supply characteristics for supply chain strategy alignment based on Lee (2002).

Demand characteristics		**Supply characteristics**	
Functional	Innovative	Stable	Evolving
Low demand uncertainties	High demand uncertainties	Less breakdowns	Vulnerable to breakdowns
More predictable demand	Difficult to forecast	Stable and higher yields	Variable and lower yields
Stable demand	Variable demand	Less quality problems	Potential quality problems
Long product life	Short selling season	More supply sources	Limited supply sources
Low inventory cost	High inventory cost	Reliable suppliers	Unreliable suppliers
Low profit margins	High profit margins	Less process changes	More process changes
Low product variety	High product variety	Less capacity constraint	Potential capacity constraint
Higher volume per SKU	Low volumes per SKU	Easier to changeover	Difficult to changeover
Low stockout cost	High stockout cost	Flexible	Inflexible
Low obsolescence	High obsolescence	Dependable lead time	Variable lead time

The warehouse role, power and placement in the supply chain need to be considered as aspects in warehouse design to ensure that the warehouse is not designed for suboptimal conditions or to support a different type of supply chain. These aspects are decided in the supply chain strategy. A warehouse can have many different placements in a supply chain network. (Frazelle, 2002) The placement in the network affects the supply and demand uncertainties. The longer the distance from the end customer the more significant is the demand volatility, often referred to as the bullwhip effect. The bullwhip effect causes larger variations in the demand for every upstream actor regarding both ordered amounts and number of orders. The same goes for the supply uncertainty which is increasing with the distance from production. (Lee et al., 1997)

Experience and resources are constraints that can affect the ultimate choice of strategy. (Selldin & Olhager, 2007) Fast growing companies are affected by these constraints as the experience on expanding and bigger operations within the company can be limited. Further, the constraints are especially distinguishable if the company is growing faster than the acquiring of resources, both regarding employees and investments. Selldin and Olhager (2007) discuss that many companies might not have the power to design their own supply chain but must adapt to an up- or downstream actor in the supply chain network. The power of each actor in the supply chain is often determined by the size of the actors' purchasing power or uniqueness. (Edgren & Skärvad, 2014)

The type of warehouse is determined by the objective of the warehouse. The three types of warehouses are distribution, production and contract warehouses. Distribution warehouses can either consolidate units handled within the warehouse, SKUs (Stock Keeping Units), from different suppliers or break-up unit loads to distribute smaller quantities. Local and regional warehouses that have the purpose to fulfill customer orders are seen as distribution warehouses. Production warehouses handle raw material, work in progress and finished goods and often have significantly fewer inflows than outflows. (Rouwenhost et al, 2000; Gu et al., 2010) Additionally, van den Berg and Zijm (1999) describe contract warehouses, which is warehouses run by a 3PL provider. As shown in table 2.2, the warehouse types are differentiated by the purpose, warehouse characteristics and common design criteria.

The design criteria commonly used for the different warehouse types can be used in trade-off situations in the design process. Design criteria can be viewed as the performance measurements of the warehouse design. The design criteria should be determined in the initial steps of the design process and used for evaluation in the last steps where the preferred solution is identified. (Gu et al., 2010) Decision criteria for warehouse design consider both the warehouse facility design and the operations within the warehouse (Rouwenhorst et al., 2000; Gu et al., 2010). Minimizing operational cost in a warehouse is a design criterion present for both distribution and production warehouses. The cost tends to focus primarily on minimizing the required work force. (Rouwenhorst et al., 2000). For contract warehouses the design criterion to minimize double handling is based on the same grounds as its aim is to minimize non-value adding labor which will reduce operational cost. The main difference between a distribution and a production warehouse is the focus on maximum throughput or storage capacity. A contract warehouse has a large inventory turnover and have unpredictable demand which leads to an increased importance of flexibility towards changes in volume and product mix. (van den Berg & Zijm, 1999) Frazelle (2002) states that due to changes in the business climate the warehouse role in the supply chain network is changing why flexibility has become a success factor for all warehouses.

A warehouse can play different roles at the same time in a supply chain. In small companies it is common that production warehouses fulfill external customer orders which means that the warehouses also functions as distribution warehouses. Some companies rent out overcapacity to other companies which would make the warehouse partly contracted. These hybrid warehouses commonly have mixtures between the purposes, warehouse characteristics and design criteria. (Bartholdi & Hackman, 2014; Frazelle, 2002)

Table 2.2. Warehouse Types (Rouwenhorst et al., 2000; van den Berg & Zijm, 1999)

WAREHOUSE TYPE	PURPOSE	WAREHOUSE CHARACTERISTICS	COMMON DESIGN CRITERIA
DISTRIBUTION	Fulfill external customer orders	Large number of SKUs. Quantities per order line small. Complex picking process. Often optimized for cost efficient picking.	Maximum throughput, minimal investment and operational costs.
PRODUCTION	Store raw material, work in progress and finished products associated with a manufacturing process.	SKUs are in storage for long period of time. Inexpensive storage systems. Bulk storage. Few orders with many order lines or large quantities per order line.	Storage capacity, minimal investment, operational cost, response time
CONTRACT, 3PL	Provide warehousing as a service to customers.	Standardized storage system. Unpredictable demand.	Minimize double handling, maximum throughput, volume and mix flexibility.

2.1.2. Storage Handling Unit Effect on Warehouse Design

In a supply chain, products are often handled in units of decreasing quantity with each node in the network that is visited. From production, finished products are packed in the largest handling unit down to the retail store where consumers purchase single articles (Bartholdi & Hackman, 2014). For this reason, the packaging system of a product is often divided into three levels, tertiary, secondary and primary package. Each level of packaging consists of a number of lower-level packages. Tertiary package is the largest handling unit of the product and is often a shrink-wrapped pallet or a roll cage. The secondary package, often referred to as retail package, is typically a carton, case, tray or simply plastic shrink film around a certain amount of individual products. The primary package, often referred to as consumer package, is the packaging that is closest to the product. The product is unitized in amounts and sizes that the end consumer demands. (Saghir, 2004) Within a warehouse products are handled in these different units but is then often called storage handling units. In warehouse literature and research the three different packaging system levels are often mentioned as the pallet, case and piece. Where a pallet load is the largest standardized material handling unit and a piece is the smallest unit handled. Figure 2.3. shows an example of a product's handling unit levels as the packaging system levels are named in warehousing literature. The carton is the equivalent of secondary packaging and unit pack is equivalent for the primary packaging. (Rouwenhorst et al., 2000)

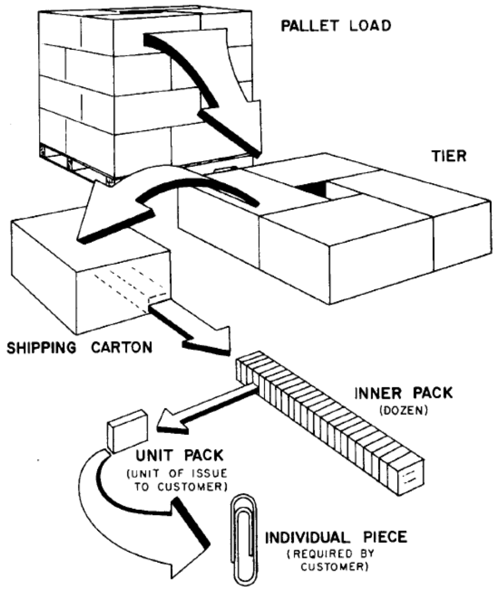


Figure 2.3. Handling units in a warehouse (Bartholdi & Hackman, 2014)

Each handling unit can be a SKU in a warehouse. This means that the same kind of product can be considered as several types of SKUs, one for each level of handling unit. The handling units in a warehouse will determine the need of equipment as well as require different types of operational strategies and warehouse layout formations. (Bartholdi & Hackman, 2014; Rouwenhorst et al., 2010)

Considering handling units, warehouses can be differentiated as unit load warehouses and break-up warehouses which breakup storage handling units to the next, lower level. Unit load warehouses handle only one type of handling unit in the warehouse and is therefore receiving and shipping the same level of the packaging system. This is typical for cross docking and for production warehouses. Break-up warehouses receive a higher level of handling unit and ships lower level units consolidated into orders in either cartons or pallets. A common example of break-up warehouses is distribution warehouses. In a unit load warehouse only one type of handling equipment is needed while in a break-up warehouse there is a potential need for different kinds of equipment as orders are consolidated. (Bartholdi & Hackman, 2014)

2.1.3. Warehouse Material Flow Effect on Warehouse Design

The traditional view of warehousing, that its mission is to store, reconfigure and shorten lead times, has been challenged and become more complex. The process flow within a warehouse can be described in six primary activities shown in figure 2.4. Lately ancillary activities have been allocated to the warehouses. Among the ancillary activities are handling of returns, repacking and final assembly from production. Due to the changing nature of the ancillary activities the placement in the process flow can be questioned. The following section describes the activities within the warehouse process.

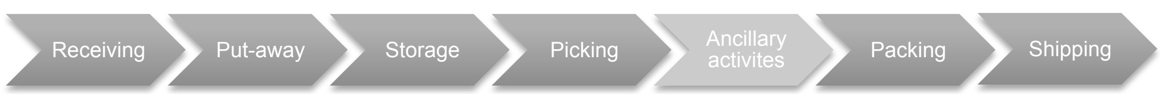


Figure 2.4. The process flow within a warehouse based on Bartholdi and Hackman (2014)

The receiving is the first activity that an arriving SKU encounters. Receiving includes receiving order receipt from sender, quality control, inspection of goods, giving it a storage location assignment and, sometimes, labeling of the SKU. (Bartholdi & Hackman, 2014) To be able to handle the incoming goods, docks must be available for incoming trucks or other vehicles as well as available floor space for the receiving activities.

In the put-away the SKU is moved to the assigned storage location. As well as putting the item away, it must also be recorded what amount and where the item is moved. In put-away the highest level of storage handling unit is handled. This often means full pallet loads which means that the equipment being able to handle pallets are a necessity as well as space as in aisles to access storage locations. If the put away regards cartons it is often possible to handle them manually or with conveyor belts. (Bartholdi & Hackman, 2014)

It is easy to believe that the main activity in a warehouse is the storage activity however there are more activities conducted in a warehouse. With more activities comes a more complex flow as shown in figure 2.5. The warehouse activities are visualized in the figure where the arrows are activities including a movement of a SKU. The squares represent activities that have space dedicated to it. The storage areas in figure 2.5 are the reserve, case pick and broken case pick. In the reserve area SKUs are stored in the highest level of handled storage unit often in pallet or other bulk storage. The areas dedicated case pick and broken case pick are often called forward pick areas. The forward pick area is defined as the areas where SKUs are stored for easy retrieval of picking unit. They are often placed to minimize travel to and within the forward pick areas to increase picking speed and reduce labor cost. The forward area can contain any handling unit thus only focusing on the turnover of the SKUs, not only case or broken case. The reserve and the forward pick area are sometimes placed as different types of departments within the warehouse. It is common for warehouses handling pallet loads and cases to have the floor level in the pallet rack as the case picking area and the upper levels in the rack as reserve. Which SKUs are stored in the forward pick area can be determined by the number of times the SKU is requested as well as the cubic flow of the SKU.

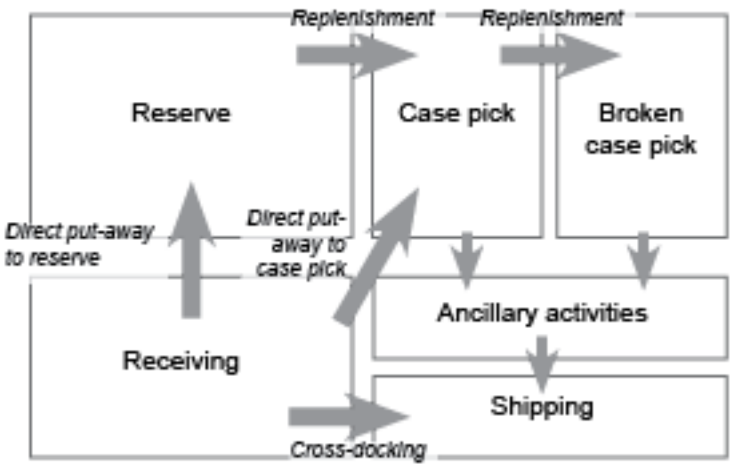


Figure 2.5. Warehouse functions and area interactions based on Tompkins et al. (2010)

The storage essentially consists of the physical containment of the SKUs. To facilitate and increase efficiency in the warehouse it can be divided into several departments with different kinds of storage systems dedicated to different types of SKUs. (Gu et al., 2007) Frazelle (2002) describes a concept, *warehouse within a warehouse*, shown in figure 2.6, where a common receiving, shipping and reserve area serves a fragmented storage area. The SKUs have been divided into groups or product families. The groupings of SKUs can be based on the product requirements, popularity, storage handling unit or company if in a 3PL warehouse. Ideally the received SKU is stored in one place until it is demanded and picked up for the next activity in the warehouse. However, the SKU can be moved to another storage location to avoid honeycombing or to conduct replenishment from a reserve area. (Tompkins et al., 2010; Accorsi et al., 2013). The efficiency of the equipment setup in a warehouse, combination of racks and material handling equipment, can be measured as storage density. The storage density is the floor space required per pallet position with the setup.

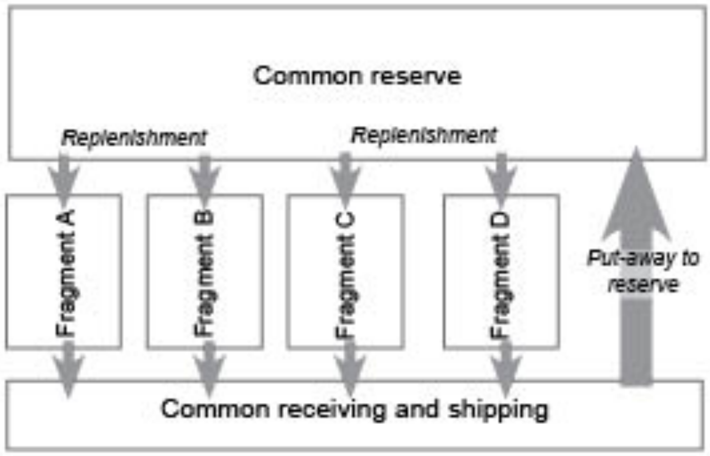


Figure 2.6. Warehouse within a warehouse inspired by Frazelle (2002)

Connecting the storing of goods to the picking activity is the dispatching of SKUs. Dispatch policies are commonly researched within manufacturing and queuing theory. (Howard & Marklund, 2011; Lee, 2006) A warehouse can be modeled as a queuing system where SKUs arrive to the queue and are stored until they are and dispatched and shipped in a certain order. (Bartholdi & Hackman, 2014) The dispatching policy used in a warehouse is determined either by optimizing operating costs or by the products characteristics. Most warehouse research considers a Last-in-first-out (LIFO) policy as it is often convenient when handling material in a model. However, it is not often the case in reality as most warehouses handling consumer goods needs to ensure freshness of products. In this case a First-in-first-out (FIFO) policy is a more accurate policy. (Lee, 2006) A similar policy to FIFO is First-Expired-First-Out (FEFO), which also is common when handling perishable or fresh goods (Bartholdi & Hackman, 2014).

Order picking is the activity where units are moved from the storage for a customer order. Picking is the activity around which many warehouses are designed. Gu et al. (2007) state that managing the order picking process requires organization of the orders to be picked and of the material handling operations of the picking. Order picking is either labor intensive or investment intensive depending on the equipment and type of dispatch policy used. When considering picking equipment one can differentiate among pick-to-person and person-to-pick type of equipment. To reduce warehouse labor or travel time for pickers, which is the most labor intensive parts of the picking activity, equipment that transport the items to the picker can be introduced in the warehouse such as conveyor belts or AS/RS systems (Gu et al., 2007). However, these systems are often expensive and inflexible as they are expensive to change (Bartholdi & Hackman, 2014). Order picking is conducted for different storage handling units such as pallet picks, carton picks and piece picking. The different types of unit picks require different material handling equipment, routes and design of racks and warehouse layouts. The storage handling unit picked in combination with the equipment choice determine the number of items that can be picked in one route. If multiple picks per route are feasible the length of the route will be affected by aisle configuration as a multiple picks route depend highly on the location-to-location distance. (Roodbergen et al., 2014) Picking pallets or other large unit load sizes often means a single pick per route. This means that the main part of travels go from the ports to a storage location back to the ports. To reduce dead heading, the times equipment travels without load, dual commands can be introduced which means that a route would consist of one put-away and one pick action. This would lead to travel between pallet locations in every cycle. For location-to-location and ports-to-location different types of aisle configurations are optimal. (Bartholdi & Hackman, 2014)

An increasing trend in the supply chain is to postpone activities to reduce bounded capital and risk for obsolete inventory. This has led to an increased amount of ancillary activities being conducted within warehouses such as labeling, kitting, packing, repairs and assembly. The ancillary activities affect the layout of a warehouse as they often require space and special equipment. (Tompkins et al., 2010; Bartholdi & Hackman, 2014; Twede et al., 2000) When determining the objective of the warehouse the ancillary activities and services that the warehouse should provide must be considered. When designing the layout the process flow in the warehouse and all activities need to be taken into consideration when allocating space to workstations to minimize wasted time for transporting SKUs around the warehouse.

After picking and/or any ancillary activities the SKUs need to be packed according to the customer order. The packing process can include a sorting element and a check for order completeness which can require special equipment or space. Packing of an order looks different depending on the handling unit of the SKUs. Packing in a unit-load warehouse might consist of putting all the pallets in one order in one lane on the shipping square. While carton or piece picking activities might incur packing products on pallets, into cartons or a combination of the two. (Bartholdi & Hackman, 2014) Depending on the packing process, different amounts of space dedicated to packing and packed goods must be allocated.

The shipping activity in a warehouse is the interface for outgoing material flow (Gu et al., 2007). The activity consists of allocating gates for arriving trucks or other vehicles used for transportation to customer, ensuring that the right goods is shipped and register the SKUs departure from the warehouse registry. Research on the shipping activity is limited. However, just like for the receiving activity floor space is required for the shipping activity to ensure efficient material handling and to avoid congestion and delayed shipments. (Bartholdi & Hackman, 2014; Gu et al., 2007)

2.1.4. Demand Pattern and Allocation Policy Effect on Warehouse Design

When planning a warehouse it is important to consider the space required for all processes in the warehouse. The space requirements for the processes are determined from careful consideration of the current activity profile in the warehouse and the growth expectations of the company. (Rouwenhorst et al., 2000; Gu et al., 2010) In research on frameworks for warehouse design the importance of designing a warehouse capable of accommodating future growth expectations of the company is mentioned. (Rouwenhorst et al., 2000; Gu et al., 2010) However, books, case studies and other more practical literature fail to take this into consideration when planning the need for space requirements. Growth expectations of a company are often forecasted based on corporate strategy, trends in previous demand as well as trends in the market such as introduction of competitors etc. Figure 2.7. shows the life-cycle phases which products and industries generally go through; introduction, growth, maturity and decline (Cox, 1967). It is important to consider in which phase the company and products are in to enable a reasonable warehouse design that will prove flexible in the future for both expansion and downsizing of the warehouse. (Karniouchina et al., 2013) There are two types of growth that affect the activity profile in a warehouse, overall demand increase and an increase of SKU types.

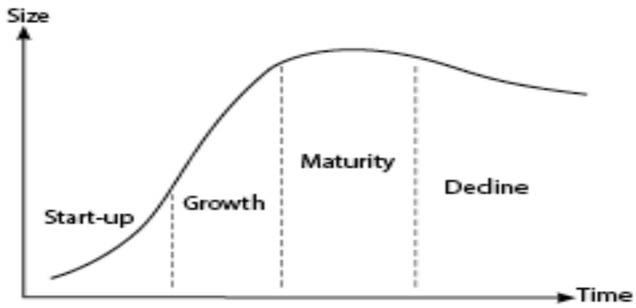


Figure 2.7. Graph over the business life cycle based on Cox (1967)

When considering the need for space in a warehouse it is important to consider the demand pattern and seasonality, both of the total overall demand but also among SKUs. Figure 2.8. and figure 2.9. visualize one of the most difficult decisions to make regarding how big portion of the peak storage requirement to accommodate. (Frazelle, 2002) If the peak is short lived and has a high peak to average ratio Frazelle (2002) suggests that a temporary storage such as a tent or truck outside the warehouse could be utilized. If the ratio of the peak to average is low and the duration of it is extended the warehouse should be sized at or very near the peak requirements.

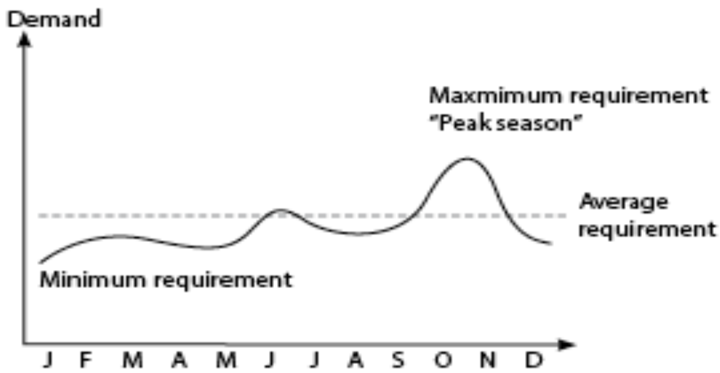


Figure 2.8. Example of seasonality over one year with small peak-to-average ratio. Inspired by Frazelle (2002)

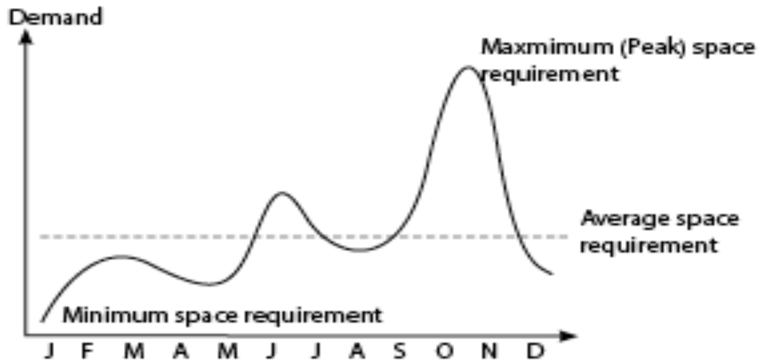


Figure 2.9. Graph of seasonality over one year with high peak-to-average ratio. Inspired by Frazelle (2002).

Frazelle (2002) highlights another important consideration in storage requirements planning, the portion of warehouse locations that will be occupied for planning purposes. Productivity and safety declines exponentially for every percentage point increase in storage occupancy after 86 %. In warehousing it is generally beneficial to have a utilization of around 80 % to ensure efficient operations. However, few warehouses have over 70 % in storage utilization.

The processes in a warehouse have different space requirements. Receiving and shipping docks need sufficient space to enable efficient handling as well as adjacent floor space for packing or sorting of the orders. The space requirement for the docks is based on the number of docks and the turnaround time for each dock. (Frazelle, 2002) Picking and put-away need aisle space to be able to maneuver and access SKUs and is primarily determined by the space needed for handling equipment. One of the most space-requiring processes in a warehouse is the storage process (Frazelle, 2002). The space requirement for the storage process is largely dependent on the storage allocation policy. There are two major storage allocation policies, dedicated and shared, also known as fixed or random storage. In dedicated storage each SKU has a fixed storage location and no other SKU is allowed to be stored in that location. Shared storage implies that the SKUs within the warehouse share the available locations so that a SKU can be placed in different locations on different occasions. A dedicated storage policy will require less administrative work as each SKU type require enough space to be able to hold its maximum inventory level and its location can be learned by the staff. A shared storage system requires more control of the inventory in stock and which position it currently holds. Therefore it often requires control on individual SKU level and not just the SKU type. Research on storage policies' effect on operational costs show that a shared storage policy can reduce travel time in a warehouse as it will require less storage space when all SKU types are likely to have different inventory levels in relation to its maximum. (Rouwenhorst et al., 2000; Tompkins et al., 2010)

In many warehouses a combination of these storage policies are used. An example is class-based storage where a SKU has a fixed zone, based on for example its popularity, but within the zone the SKU may be placed in any random location. A warehouse can also have different storage policies for different SKUs. A common practice is to have a dedicated storage policy in the forward pick area to facilitate picking and have a shared storage policy in the pallet reserve area to save space. (Cormier & Gunn, 1992)

Calculating the needed storage space requirements for pallet storage can be conducted in a number of ways depending on the storage allocation policy. When using a dedicated storage policy, the maximum number of units per SKU needs to be available for all SKUs. (Tompkins et al., 2010) This means that the total number of storage locations needed is calculated as the sum of maximum levels for all SKUs. In a warehouse with a dedicated storage policy the theoretical storage location utilization is determined as the safety stock level plus the average of the reorder quantity divided by the total number of storage locations. (Bartholdi & Hackman, 2014) This means that the utilization of the storage locations depends on the level of safety stock. If safety stock is not considered the storage location utilization will be around 50 % in a warehouse with a dedicated storage policy.

Calculating the need of pallet locations is more difficult when a shared storage policy is used as the maximum number of pallets in store is dependent on how the cycles of inventory replenishment are overlapping. A common way to calculate the required number of pallet positions needed in a shared storage system is to calculate the sum of the average number of units in store per SKU (Bartholdi & Hackman, 2014). However, this does not take into consideration that the replenishment cycles for the different SKUs can be overlapping. Tompkins et al. (2010) suggest that a historical overview of the number of units in store per SKU over a time period is considered to identify the total maximum number of units in store per cycle. Frazelle (2002) suggests that the number of storage locations required is calculated with the help of forecasted annual demand, inventory turns per year, ratio of *peak-to-average*, portion of peak inventory to accommodate and desired location utilization factor. The floor space can thereafter be calculated as the number of unit locations required multiplied by the storage density. (Frazelle, 2002)

2.2. Aspects Connected to the Warehouse Design Process

Aspects to consider in the warehouse design process that have a direct influence on the warehouse facility and interior design are space requirements and product requirements. Product requirements on this level refer to the environment in the warehouse and roughness of material handling. (Bartholdi & Hackman, 2014) The space requirements are connected to the rack and equipment selection, which in turn is dependent on the level of automation required for the warehouse. (Naish & Baker, 2004) The level of automation can be divided into four levels; manual labor, mechanical assistance, simple automation and complex automation. The decision regarding level of automation in the warehouse is determined by the flexibility wanted, labor cost, rent and throughput. (Naish & Baker, 2004; Bartholdi & Hackman, 2014) Further, aspects such as enabling efficient handling and storage location convenience are aspects that should be taken into consideration when designing warehouse layout suggestions. (Bartholdi & Hackman, 2014)

2.2.1. Product Requirements on the Warehouse

One of the primary tasks of a warehouse is to store goods why the product itself must be of key concern when designing a warehouse. In this section main product requirements will be covered together with how the packaging system affects the storing of the goods. The product requirements should be considered when selecting equipment and choosing a warehouse layout (Tompkins et al., 2010). A product requirement can be level of temperature and moist in the atmosphere, perishability of the product and sensitivity to impact and rough handling. The packaging of a product has some main functions that can reduce the impact of the product requirements; containing, protecting, apportioning, unitizing and communicating. For example can focus on good containment and protection allow for greater freedom in handling and transportation. A communicative package can allow for more efficient handling by having bar-codes enabling scanning and being easier to identify. (Lockamy, 1995)

Common specialized warehouses that serve products with special requirements are spare parts warehouses, warehouses for perishables and e-commerce warehouses. When handling spare parts, the requirement is primarily to hold as many different items as possible to be able to serve customers. Perishable goods like fashion items and food have a high inventory turnover in common. The perishability of a product is an aspect to consider when selecting equipment setup as the dispatch policy in the warehouse needs to be considered. Temperature considerations are also often important when handling perishable goods such as food. E-commerce warehouses often pick pieces which means that the operations are very labor intensive. Further, e-commerce warehouses are subject for high rates of returns, which often can reach 25-30%. (Bartholdi & Hackman, 2014)

Further, many products have special requirements. Among these requirements are security for high value goods, safety for flammable or hazardous liquids and aerosols and temperature for chilled or frozen goods. These requirements must be highly considered when developing the real estate to be able to be effective in the handling of the goods i.e. not damaging the goods, the facility or employees. Grouping the products into families considering these special requirements and storing the together in special zones can also help the efficiency of the warehouse. By reducing the need for special equipment and special handling costs can be kept to a minimum. (Bartholdi & Hackman, 2014) Overall, research on zoning is scarce (de Koster et al., 2007) much of which focusing on picking efficiency (such as de Koster et al., 2012 and de Koster et al., 2007) and not the warehouse's ability to handle goods without damage.

2.2.2. Decisions on Equipment and Level of Automation for Material Handling

When considering the level of automation in a warehouse it is common to consider labor cost and cost of space in relation to investment cost of the automated system (Bartholdi & Hackman, 2014; Frazelle, 2002). The research on benchmarking warehouse operations conducted by Hackman et al. (2001) show that warehouses with low levels of automation is often more efficient. This trend is more visible in small firms, which means that the level of automation can be dependent on the size of the warehouse throughput. Naish and Baker (2004) present framework for assessing if and to what extent an automated solution is applicable for a warehouse. Figure 2.10. shows a basic framework on how to select equipment type based on the total number of SKUs in the system and the system throughput. The higher the number of total SKUs and the higher the total throughput the more suited is the system for automation while lower numbers make manual labor sufficient. (Naish and Baker, 2004)

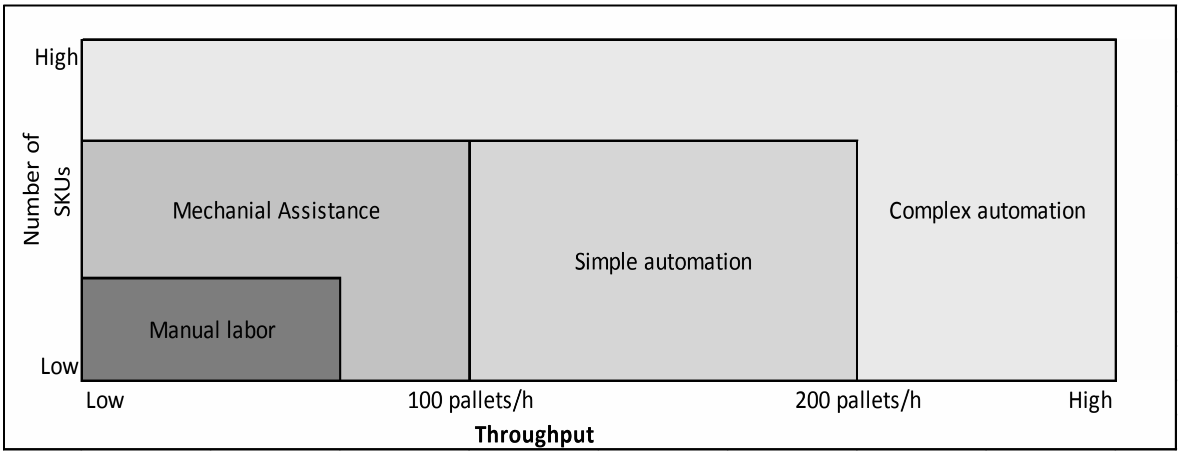


Figure 2.10. Basic framework on how to choose equipment based on Naish and Baker (2004)

Manual labor includes shelf picking and movements primarily made by hand pallet lifter since both the throughput and the total number of SKUs is low. If either the throughput or the number of SKUs rises, mechanical assistance might be needed to enable efficient warehouse operations. These include motorized forklifts to put pallets into rack systems or conveyors to assist transportation. With even higher throughput, simple automation might be suitable. Simple automation includes AS/RS systems for specific unit-loads, e.g. cranes in a pallet-in-pallet-out warehouse, and conveyor systems. With a high throughput and high number of SKUs complex automation systems are suitable. These systems are often pick-to-person systems with build-in sorting systems and complex conveyor systems. (Naish & Baker, 2004)

2.2.3. Aisle Configuration and Lane Depth

Designing the layout of a warehouse is a highly complex decision as it involved the coordination of labor, equipment and space. According to Tompkins et al. (2010) the objectives of a warehouse need to be set before designing the layout. The objectives of a warehouse layout are to; use space efficiently, allow for the most efficient material handling and provide the most economical storage. The objectives should be put in relation to cost of equipment, use of space, damage to material, handling labor and operational safety. It should also provide maximum flexibility in order to meet changing storage and handling requirements and make the warehouse a model of good housekeeping. A warehouse layout design considers the placement of receiving and shipping docks, aisle configuration and equipment setups storage potential such as lane depth and stacking height. (Tompkins et al., 2010)

The convenience of storage locations in a warehouse is determined by the material flow in the warehouse, which in practicality means that the placement of receiving and shipping docks is the main aspect. Figure 2.11. shows an example of storage positions and their convenience. The convenience of a storage location is determined by the amount of travel that is needed to put-away and pick the SKU considered. A minimum amount of travel is considered convenient. (Bartholdi & Hackman, 2014) This means that the right pallet position is the most convenient as that pallet location requires less travel from the receiving to the shipping represented by the round dots.

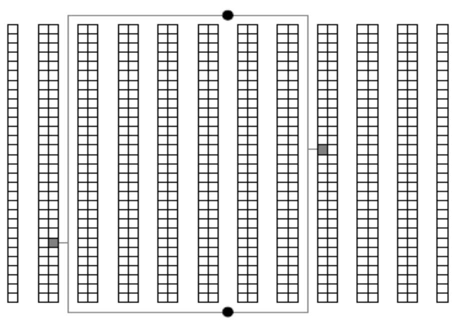


Figure 2.11. The right location is more convenient than the left location as the distance traveled is shorter (Bartholdi III & Hackman, 2010)

Two common ways of locating receiving and shipping docks is either on opposite sides of the warehouse, flow-through, or on the same point in the warehouse, U-flow as shown in figure 2.12. The placement and number of convenient locations (dark color) is different. The degree of convenient locations has impact on the efficiency of class based storage policy. (Bartholdi & Hackman, 2010) The flow-through layout has many equally convenient locations however, no locations are especially convenient. It is appropriate for high material flows as the traffic from the forklift trucks for put-away and picking does not have the same route patterns and the docks for shipping and receiving can be specialized to a higher extent. However, this limits the opportunities for efficiency gains in equipment utilizations by dual transactions in put-away and picking. The U-flow layout is highly appropriate when the SKUs in the warehouse have a strong ABC skew, i.e. a few SKUs accounts for a high percentage of the activity. The U-flow also gives more opportunities for increased equipment utilization by using dual commands as well as the benefit of sharing the receiving and shipping docks. Sharing of docks is suitable when the pressure on receiving and shipping docks vary thus being able to use the docks for both activities interchangeably. The two layout models have different opportunities in expansion of the warehouse. The U-flow has an opportunity for expansion in three directions while the opportunities are limited in the flow-through model by the docks on two sides. (Bartholdi & Hackman, 2014)

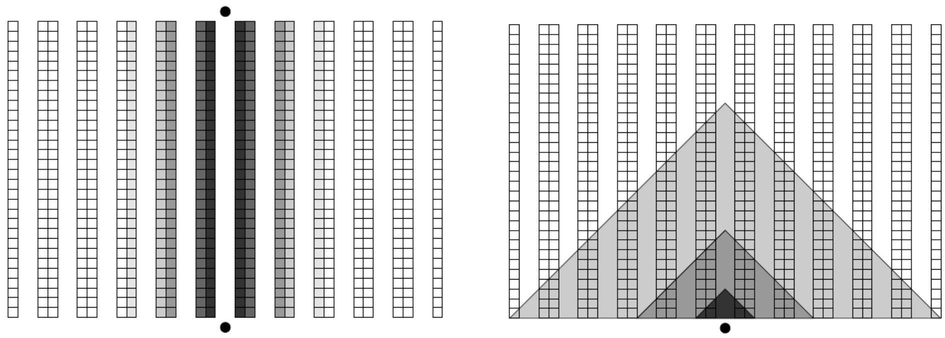


Figure 2.12. Receiving and shipping dock placements, flow-through (left) and U-flow (right) (Bartholdi and Hackman, 2014)

There are numerous types of aisle configurations that all have different benefits. The most common aisle layout described in literature is rectangular with or without broken aisles as shown in figure 2.13. The fishbone layout is developed to facilitate picking and lower the travel distance per route. (Bartholdi & Hackman, 2014) However, Roodbergen et al. (2014) state that the travel distance in a fishbone layout is longer if the route includes multiple picks.

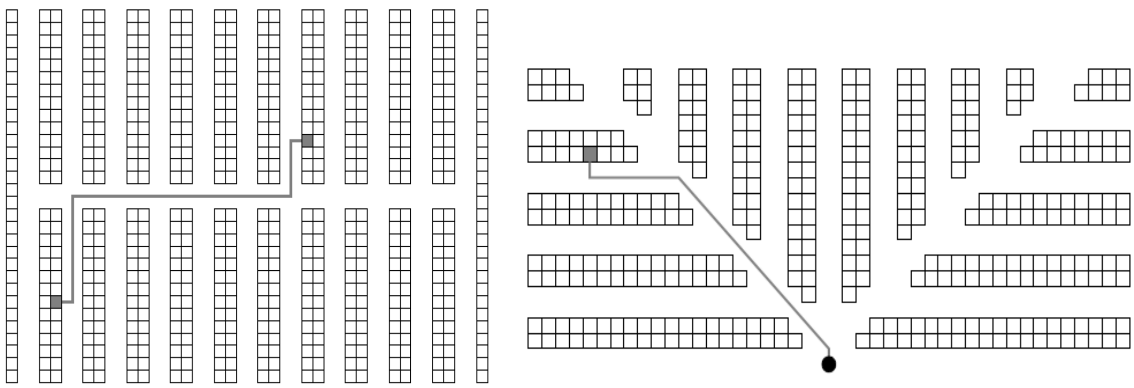


Figure 2.13. Aisle configuration layouts. Rectangular with broken aisles (left) and fishbone layout (right). (Bartholdi & Hackman, 2014)

When considering the warehouse layout and aisle configuration it is important to consider the trade-offs between efficient material handling and storage density. To ensure efficient material handling between receiving and shipping it is important to place aisles in line with the material flow. Narrow aisles ensure higher cube utilization since a higher volume will be dedicated to racks. However, it will hamper the material handling as the ability for multiple picks in the same aisle is reduced. Wide aisles will make simultaneous picks possible but lower the storage density. In the same way, the number of aisles affect the utilization. A high number of aisles bring good mobility, accessibility and possibility to find short paths but also occupy space in contrary to low number of aisles, which is cube efficient but also provide low access to the pallet positions. (Hassan, 2002)

Depending on the design of the picking activity, facilitating the movement between storage locations can lower the total travel time. Introducing cross aisles in a rectangular layout or using a fishbone layout can increase material handling efficiency but will result in lower storage density in the warehouse. It is important to consider the cost of material handling in relation to the facility cost of increased space need. (Bartholdi & Hackman, 2014; Tompkins et al., 2010; Roodbergen & Vis, 2006) Research suggests that to minimize the floor space needed for storage a warehouse should be designed with aisles parallel to the long side of the building, storage lanes placed along interior walls and space utilization such as over-aisle storage or over-dock storage and covering building columns in storage racks should be considered. (Frazelle, 2002; Tompkins et al., 2010)

Considering the storage system space utilization it is not only aisle space that should be considered. Honeycombing is wasted space that results when a partial row or stack cannot be utilized because adding other SKU types would block storage. To increase the number of storage locations per floor area, SKUs that are stackable are stacked as high as possible and unstackable SKUs are placed in racks. Stacking SKUs on top of each other is a cheap way of storage as it does not require any investments in racks. However, it makes the SKUs that are not on top inaccessible and results in potential vertical honeycombing waste. The economic argument on how many racks that should be bought depends on the size and movement pattern of a SKU. Reasons for investing in racks can be to facilitate material handling, increase accessibility, reduce product damage by forklifts and provide a safer work environment. The benefits from putting a SKU in a rack should justify the cost of the rack. (Bartholdi & Hackman, 2014)

To decrease wasted space due to aisles many warehouses use racks or lanes that are more than one storage position deep as shown in figure 2.14. The aisle space needed per pallet position is half of the aisle divided by the number of pallet positions in depth. The amount of aisle space per storage location is therefore decreased with every additional pallet position deep. An example of the benefits is that a double-deep rack will yield 41% more storage positions than a single-deep rack using the same floor space thus increasing the storage density. This means that deeper lanes produce more pallet positions but they are of a lower value as only portions of them are accessible. As a result, honeycombing will be an issue. If the rack is not full, the utilization drops. Deep racks can require forklifts or other mechanical or automated aid to enable reach to the SKUs left at the back of a rack which potentially can increase equipment cost in warehouses. (Bartholdi & Hackman, 2014)

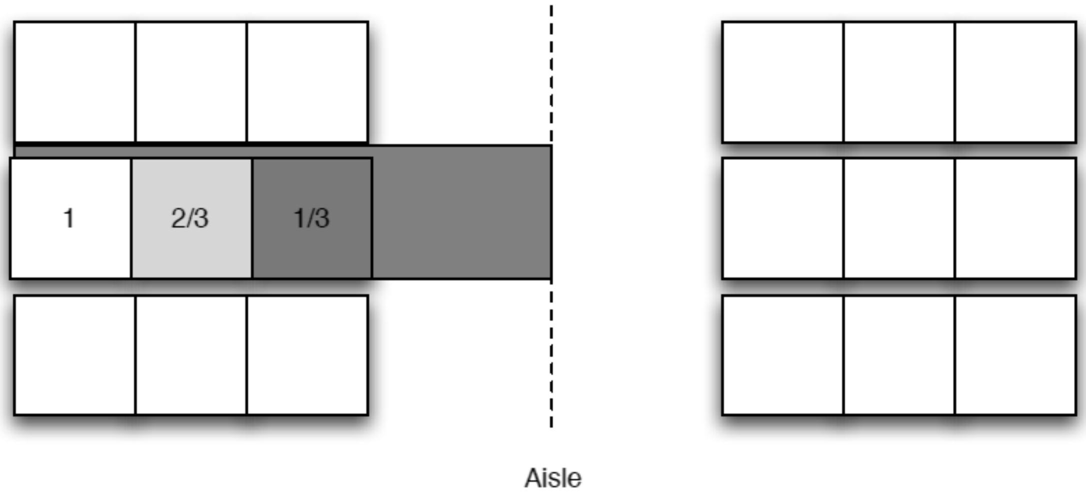


Figure 2.14. Example of 3-deep storage racks. The figures explain the rate of utilization if containing 1,2 or 3 pallets (full rack). (Bartholdi & Hackman, 2014)

To calculate the optimal lane depth many aspects can be considered such as travel time (Tompkins et al., 2010), space utilization (Bartholdi & Hackman, 2014) and equipment cost (Frazelle, 2002). Considering the travel time in relation to lane depth, if a SKU is stored in six units the distance in the aisle to the one furthest away in a single-deep rack is six units away. However, if the racks have lanes that are three positions deep the distance in the aisle to the SKU furthest away is two units (Tompkins et al., 2010). Optimizing lane depth (D_l) considering space efficiency can according to Theorem 6.1 in Bartholdi & Hackman (2014) be calculated with the formula:

$$D_l = \sqrt{\left(\frac{q_i}{z_i}\right)\left(\frac{a}{2}\right)}$$

where q_i is the order quantity for SKU i, z_i is the stacking height for SKU i and a is the aisle width.

Considering the equipment cost as an optimization parameter the cost of equipment setup needs to be taken into consideration. Commonly used racks are single-deep, double-deep, push-back, flow-though and drive-in/through. Between each type there are differences, which can be a crucial decision for the overall efficiency of the warehouse. The single-deep is, as the name suggests, one position deep while the double-deep is two. The flow-though, push-back and drive-in racks have no limit in lane depth and is therefore halted by its own feasibility. The primary material handling equipment for pallet-load warehouses include forklifts such as counterbalance lift truck, reach and double-reach truck, turret truck and more automated equipment such as stacker cranes within an AS/RS. As with the racks, there are significant differences between the types regarding both vertical and horizontal velocity, reach and required aisle space. (Bartholdi & Hackman, 2014) The lane depth chosen will affect the investment cost of racks and therefore equipment. To optimize the lane depth considering equipment cost the winning combination of material handling equipment and racks is the most cost efficient combination.

A strict dispatch policy in a warehouse can restrain the choice of equipment setup and might increase importance on warehouse control as the need to keep track of the time of arrival of SKUs increase. To reduce the risk of double handling, the rack types must be chosen to support the dispatch policy. When a LIFO policy is used, racks with deep lanes accessible from one aisle can be used since the last SKU to arrive will be the accessible SKU. Considering a FIFO policy the same type of racks would incur double handling of SKUs as the blocking SKUs would need to be removed in order to access the oldest SKU. Racks that enable accessibility of the oldest SKU will be more appropriate for FIFO warehouses such as single racks or flow-through racks. Using single-deep racks for either policy will not increase double handling, however it will require a system to keep track of the time of arrival of every SKU as well as its location. (Bartholdi & Hackman, 2014; Frazelle, 2002)

3. Methodology

Research methodology is a tool that enables researchers to reach the goals set in the research study. Having a method is a necessary premise towards conducting a serious research study. (Holme & Solvang, 1997) To consider the research methodology early in the research process is important to ensure that the study does not become unplanned and hard to finish (Denscombe, 2009). Making a well-informed choice regarding research strategy and design is essential for the process towards answering the research questions. There are several important choices to be made when deciding a suitable and logically designed research methodology among which are research strategy, research techniques and procedures. (Saunders et al., 2009) The research strategy should suit the purpose of the study. The purpose of a study can be descriptive, exploratory, explanatory or problem solving in nature. It is common that master thesis studies in engineering are problem solving with hints of other purposes. (Höst et al., 2002) When deciding the research strategy it is also important to consider the type of research questions and thereafter the research design. In the research design an explanation of how data will be gathered and how it should be analyzed to find an answer to the research study are elaborated. (Voss et al., 2002) According to Kovács and Spens (2005) many researchers within logistics have found the subject interdisciplinary by definition why the methodologies originates from different scientific traditions. It has been influenced not only by economic and behavioral approaches, mainly through the business disciplines of marketing and management but also by borrowing from engineering. For this reason various methods has been used in logistics research from mathematical modeling and simulation to survey research and from case studies to interview methods. (Kovács & Spens, 2005)

The methodology used in this thesis is described with the research strategy which describes what type of research will be conducted, research design which will describe how the data collection and analysis in the empirical part of the study was conducted. The data analysis also describes the practical workflow in the project and thoroughly describe the framework developed from the frame of reference. Research quality is assured by considering triangulation, validity and reliability of data and results throughout the study.

3.1. Case Study as Research Strategy

Eisenhart (1989) defines a case study as a research strategy which focuses on understanding the dynamics present within single studies while Yin (2003) defines it as an empirical inquiry that investigates a contemporary phenomenon within its real life context. Höst et al. (2011) further describes the case study as description of a specific situation to understand processes performed within an organization. Although there is no single definition of a case study the research point in a similar direction. For this thesis the definition provided by Yin (2003) will form the base for the research strategy. The case study is primarily used when the boundaries between phenomenon and context are not clearly evident (Yin, 2003; Yin, 2007). This is mainly due to the nature of the case study which allows for deep understanding of the phenomenon since the research object is studied in detail within in its original context. (Denscombe, 2009) The case study will answer how the object affects and is affected by its surroundings. (Cassell & Symon, 2004) The case study relies on multiple sources of evidence, with data needing to converge in a triangulating fashion. (Yin, 2003). The sources include archives, interviews, questionnaires and observations of both quantitative and qualitative nature. (Eisenhart, 1989; Cassell & Symon, 2004) These methods may be used individually or combined. (Cassell & Symon, 2004).

Handfield and Melnyk (1998) argue that the case study is suitable for discovery, description and mapping of theory answering questions as shown in Table 3.1. Similarly, Eisenhart (1989) find description, theory testing and theory generating as purposes for a case study. In our case the questions for mapping (Handfield and Melnyk, 1998) or theory testing (Eisenhart, 1989) match our research questions why a case study is suitable.

Table 3.1. Research purpose and research questions connected to case studies as proposed by Handfield and Melnyk (1998)

Purpose	Research questions
Discovery	What is going on? Is there anything interesting enough to justify research?
Description	What is there? What are the key issues? What is happening?
Mapping	What are the key variables? What are the salient/critical themes, patterns, categories?

Case studies have been considered as one of the most powerful research methods of operations management (Voss et al., 2002). Voss et al. (2002) state three main strengths of case research. The first is that the phenomenon can be studied in its natural setting resulting in meaningful, relevant theory generated from the understanding gained through observing actual practice. Connected to Operations Management, Handfield and Melnyk (1998) argue that the practicality of the research is of key concern primarily since practicing managers are the main consumer of the research. They describe the situation as “unless we can provide these ‘consumers’ with knowledge pertaining to events which are observed and tested, managers will quickly and ruthlessly discredit the resulting research” (Handfield & Melnyk, 1998, p. 322). Second, the case study allows the questions why, what and how, to be answered with a relatively full understanding of the nature and complexity of the phenomenon. In this study the research questions are of the types what and how. Third, the case study lends itself to early, exploratory investigations where variables are still unknown and the phenomenon not at all understood. There are several types of case studies. Single cases, multiple cases, retrospective cases and longitudinal cases their advantages and disadvantages are described in table 3.2. (Voss et al., 2002)

Table 3.2.Types of case studies and their advantages and disadvantages (Voss et al., 2002).

Choice	Advantages	Disadvantages
Single cases	Greater depth	Limits the generalizability of conclusions drawn. Biases such as misjudging the representativeness of a single event
Multiple cases	Augment external validity, help guard against observer bias	More resources needed, less depth per case
Retrospect cases	Allow collection of data on historical events	May be difficult to determine cause and effect, participants may not recall important events
Longitudinal cases	Overcome the problems of retrospective cases	Have long elapsed time and thus may be difficult to do

Retrospect cases allow a more controlled case selection, for example it is possible to identify cases that have been either a success or a failure. Longitudinal cases can be of particular value as the longer the period over which the phenomenon is studied the greater the opportunity to identify the sequential relationships of events. (Voss et al., 2002) As this study is time limited to 20 weeks a longitudinal case study has not been possible to perform. A retrospect case would not have been an option as the framework developed from theory would be tested, which of natural reasons could not be done with a retrospect case.

One of the early parameters to determine when conducting a case study is the number of cases and which cases that should be used in order to conduct the research. Patton (1990) argues for the purposeful sampling. The logic and power behind the purposeful sampling lies in the selection of information-rich cases. Information-rich cases are cases that to a large extent can help the researcher find the core issues of the research purpose. (Patton, 1990) For qualitative research the amount of cases can be as low as one thus allowing greater depth. (Patton, 1990; Voss et al., 2002) Greater depth, especially regarding warehouse design, requires that the researchers have full understanding and access to relevant data for the study. (Frazelle, 2002) In this thesis a single case study is performed to reach the depth needed to evaluate the developed framework in a thorough fashion. This will according to Voss (2002) make solutions less generalizable but can lead to a greater and more in-depth understanding of the studied phenomenon. Eisenhardt (1989) means that due to the fact that within case research only one case is often studied, the results of the case studies are not necessarily applicable in other cases. This can be especially true for single case studies and is one of the limitations of the results of this study.

3.2. Research Design

Research design is the plan for how the research strategy will be implemented and used to answer the research questions and fulfill the purpose of the study. Research design can be fixed or flexible which means that it either needs to follow the initial design or can be changed during the study according to findings along the way (Höst et al., 2006). Case studies are flexible in nature as research questions as well as the purpose of the study can develop during the study (Voss et al., 2002). After conducting a literature review within the subject of warehouse design the method for the study was concluded. The method was designed by developing a framework for warehouse design that includes steps that take a company's growth expectations into consideration. Academic frameworks were used as well as frameworks from books used more frequently by practitioners to construct the framework. Existing frameworks are mainly aimed towards a design for a current situation. Therefore, there is a gap in research between design layouts aligned with the current and future demand. For this reason the effects of strategic decisions needed to be considered for the developed framework. As many of the frameworks found in literature were based on literature reviews their use was not vastly tested and documented in reality by researchers (Baker & Canessa, 2009). For this reason a case study was conducted to test the frameworks usability and refine it further.

Case sampling, choosing a case, can be done in many different ways. Patton (1990) has defined 16 different kinds of sampling mainly based on the purpose of the research. For this research the *critical case sampling* has been used. The chosen sampling method makes the sample itself a representative of the phenomenon in question by identifying the key dimensions that make the case critical. (Patton, 1990) The Oatly AB case is a good representation of the phenomenon that has been studied. The current warehouse design at Oatly AB was generated with neither adequate strategy nor growth expectations in mind. The company is in a volatile growth phase, which further puts pressure on the warehouse design solution to be aligned with the future operations as well as today's to remain cost efficient during its economic life span. Although the sample size for this research is small (single case study), logical generalizations can according to Patton (1990) be made for other companies in a similar situation. The research design will be presented by describing the research case and the methods used for the data collection and data analysis.

3.2.1. Case study in the Oatly AB Case

The case company Oatly AB, henceforth Oatly, has increased their sales volume steadily during the last eight years with an additional bump during late 2014. The placement in the industry lifecycle is analyzed as being in the beginning of the growth phase. The market for non-dairy products is growing with an estimated rate of 66.7 % from 2013 to 2019. This means that there is a lot of potential and that the growth is rather uncertain and hard to forecast for Oatly.

The growth that Oatly is facing does not only come from an increased turnover but also a more diverse product portfolio. With new products the demand for flexibility in the warehousing solution intensifies to assure that the warehouse space will be utilized optimally without affecting the handling. Rouwenhorst et al. (2000) discuss that warehouse design is a highly complex task where, in each step of the design, trade-offs have to be made between conflicting objectives such as storage efficiency and accessibility. They further state that capacity problems can lead to inefficient and expensive materials handling mainly due to double handling as well as addressing the safety issue originating from *ad hoc* storage in aisles and other undesignated areas (Rouwenhorst et al., 2000).

The current warehouse solution for the main warehouse at Oatly is not aligned with the company strategy or the supply chain strategy. The solution was designed for the former company strategy at Oatly which had a considerably lower product introduction rate and growth expectations. The concern at Oatly today mainly regards the capacity of the warehouse due to the overall space available and the current rack system in the warehouse. The solution is inflexible due to light automation and deep lanes which causes the warehouse to appear to be full although the fill rate is low due to honeycombing. Further, alignment to both production batch sizes and order quantities have not been taken into consideration when developing the current warehouse layout solution why the risk of honeycombing has increased even more. Oatly have also noticed a lack of space for in- and outbound goods as well as for ancillary activities as repacking and laboratory testing have been introduced in the warehouse.

Management at Oatly has a willingness to keep the materials handling and the warehousing as efficient as possible. The uncertainties regarding future demand align with the mission of this thesis which is to explore aspects and frameworks for generating a sustainable warehouse layout for fast growing companies. The uncertainties further demand the flexibility aspect of the research to be able to adapt to the changing environment regarding both total amounts and product portfolio. Based on the willingness at Oatly to keep the materials handling as efficient as possible as well as prepare for future challenges makes Oatly a good company to study. Management at Oatly have noticed the need for efficient warehousing, during both peak and slack, to keep costs as low as possible.

3.2.2. Data Collection

Gathered data can be either qualitative or quantitative which should be considered in relation to the purpose of the study and the nature of the subject (Höst et al., 2011). Qualitative data is expressed in words and explanations and is suited for unstructured information like thoughts, strategies and other intangible information. Quantitative data, also known as objective data, is often structured and enables immediate numerical analyses and comparisons. (Holme & Solvang, 1997) Even though case studies are often connected to qualitative data, objective data can be necessary. (Voss et al., 2002) Collecting objective data for a study can be more accurate during a case study than in for example a survey study as the researcher can have direct access to the data sources. Other sources of data can include observations, informal conversations, attendance at meetings and events, surveys administrated within the company, review of archival sources and collection of objective data. (Voss et al., 2002)

Another way of categorizing data is to divide it into primary and secondary data. Primary data is data gathered for the study and secondary data is data that is gathered for other purposes. Typical examples of secondary data often used in studies are extracts from enterprise resource planning (ERP) systems and financial data about the organization. (Höst et al., 2011) When mapping the background and current situation at Oatly secondary data was gathered through the company's website, daily newspapers from the geographical area and financial databases. Secondary data have also been extracted from the company's ERP system containing snapshots of the inventory in the warehouse was taken every working day during a month to enable analysis of warehouse utilization and forecasts of the pallet positions need in the future.

Table 3.3 describes different data recommended to use as input data for warehouse design frameworks found in literature. Many of the data points are present in many of the frameworks while others differ. Bartholdi and Hackman (2014) are the only ones taking the introduction of new SKUs into consideration, which can affect to what degree flexibility is an important aspect for the warehouse in question. The only data point that considers demand patterns and expected growth for a warehouse is the seasonality. Information about the current layout in the warehouse is gathered in four of five data gathering plans. However, the information is rarely used in relation to the development of new warehouse layouts. The current layouts often form a base regarding e.g. the dimensions of the real estate not including the interior and current material flows and processes. Therefore, the frameworks tend to keep the problem aimed towards design and not redesign.

Table 3.3. Data gathering points described in reviewed frameworks

	Bodner et al., 2002	Accorsi et al., 2014	Baker & Canessa, 2009	Bartholdi & Hackman, 2014	Govindaraj et al., 2000
Product information	X		X		X
Order profile	X	X	X	X	X
SKU data	X	X		X	X
Inbound data	X	X	X	X	
Dispatch data			X	X	X
Seasonality				X	X
Inventory data	X	X			X
Labor	X			X	
Current layout	X	X	X	X	
Service requirements	X		X	X	
Rate of new SKUs				X	

During this study much of the primary data has been found through interviews. This is in line with what Voss et al. (2002) state; the primary source of data when conducting a case study is structured or semi-structured interviews often backed up with unstructured interviews and interactions. A structured interview can be compared to a questionnaire, as all questions are determined in advance. During a semi-structured interview the interviewer has some planned questions to start the interview. However, depending on the interviewees' answers questions may be added or omitted. Unstructured interviews are fully informal and exploratory which means that all questions depend on the evolving conversation between the interviewer and interviewee. (Voss et al., 2002) In the initial studies unstructured interviews and informal conversation with employees at Oatly, primarily with Magnus Olin (Warehouse Manager) and Sofia Lindgren (Chief Operations Officer) were conducted during company visits to find the purpose of the study and the root of the problem at Oatly. Semi-structured interviews were held with Joakim Herlin (Business Controller) to enable an understanding of how the corporate strategy would affect the growth expectations of demand in the warehouse. Semi-structured interviews were held with Sofia Lindgren, Magnus Olin and Tomas Wennerholm (Supply Chain Coordinator) to prioritize the warehouse objectives and thereby how he researchers should act and make decisions in trade-off situations. The former, structured, approach was suitable based on the facts needed to be gathered while in the latter, semi-structured, approach, soft aspects as culture and other company policies might prove interesting.

Observation is a data collection method in which the researcher studies either a course of events and notices what is happening. Events which often are observed are meetings, work processes and flow of for example material and information. According to Rosengren and Arvidson (2002) there are four categories of observations influenced by the level of interaction and knowledge the observed object has about being observed. The four categories are absolute observant, absolute participant, participating observant and observing participant. (Rosengren & Arvidson, 2002) In this study the researchers will conduct observations as participating observants as they will be a part of the context, and yet not. The researchers will in no way try to hide that they are observing and will collect data through interviews, ocular inspections and recordings. This role is determined as a low interaction level with the observed object but the object has a high knowledge about being observed. This role can lead to increase trust with the studied object which can in turn lead to losing distance to the object. This risk will be alleviated in this study by triangulating data from different sources and by comparing results found with literature. The main object of observation during our study has been to observe work processes in the warehouse regarding material flow as well as consequences of lack of space in the warehouse. The observations have been conducted with the workers in the warehouse knowledge and their consent. Observations has also been done in the production facility where the pallets are mounted and labeled with the position in the warehouse in today's operations as this process is something that might be included as an ancillary activity in the warehouse in the near future.

3.2.3. Data Analysis

Gathering and analysis of data was conducted simultaneously which enabled the authors to take advantage of flexible data gathering and facilitated the starting phase of the analysis (Eisenhardt, 1989). Identified input data to each step in the framework were analyzed to develop components of the final warehouse design. Frazelle (2002) and Bartholdi and Hackman (2014) describe analysis profiles that are relevant for activity profiling before a warehouse design; customer order profile, purchase order profile, item activity profile, calendar-clock profiling, activity relationship profiling and inventory profiling. If the data used in the activity profiling is accurate the profiling quickly reveals warehouse design and planning issues that might not be observable in the operating warehouse. For this reason it is important to visualize the data to show patterns. (Frazelle, 2002)

The aim of the analysis is to find SKUs, or groups of SKUs, that should be treated differently. Finding what SKUs, and to what extent the SKUs, are consuming warehouse resources, both labor and space can help the warehouse designer to allocate SKUs in a way that minimizes operational cost. (Bodner et al., 2002) These analyses rely on *rules-of-thumb* such as the Pareto optimality (80-20 rule) or ABC analyses. The 80-20-rule assume that 20 % of the SKUs stands for 80 % of the activities while the ABC analysis classify the SKUs into three groups depending on different characteristics. (Bartholdi & Hackman, 2014) The selected profiles analyzed in each step of the developed framework are described further in the following section.

3.3. Warehouse Layout Design Framework

The development of the framework is conducted with a base in the frameworks found in the literature review. With inspiration from the categorization of the steps in the reviewed design frameworks the *warehouse layout design framework* was developed. It was then further refined through the case study at Oatly AB.

The categorization of steps found in existing frameworks is shown in table 3.4. Six categories of steps were identified in the nine frameworks reviewed. The categories functional specification and technical specification are where the reviewed frameworks differ the most. Some of the frameworks emphasize operational work procedures while other frameworks focus on more technical capabilities. Many of the steps found in the literature review has been used to develop the warehouse layout design framework.

Figure 3.1. show a visualization of the warehouse layout design framework together with an explanation of step an how the step help facilitate decision-making for a fast growing company. The framework is divided into two parts, one focusing on the purpose and requirements put on the warehouse, and one focusing on the layout planning. The warehouse layout design frameworks first part is mainly inspired by the purpose and requirements and the functional

specification. The first part of the framework creates a base for the second part of the framework. The second part of the warehouse layout design framework consists of the more physical part of the layout design and is inspired by the three last categories in table 3.4., technical specification, development of layouts and evaluation and assessment. The steps from these three categories have been chosen and altered based on their relevance for fast growing companies. The data gathering and analysis category has in the warehouse layout design framework been divided and put into all of the steps in the framework to enable flexible data gathering and analysis when it is needed. However, the step forecasting expected demand presented by Hassan (2002) which is placed in the data gathering and analysis category has formed the base for step 4 forecast and analyze expected demand in the warehouse layout design framework.

The warehouse layout design framework consists of eight steps which are described in this chapter, with each steps key questions and outputs as well as the data collection and data analysis methods suggested to answer them.

Table 3.4. Categorization of steps from warehouse design frameworks. ***[1]*** *Rouwenhorst et al., 2000;* ***[2]*** *Hassan, 2002,* ***[3]*** *Govindaraj et al., 2000;* ***[4]*** *Bodner et al., 2002;* ***[5]*** *Tompkins et al., 2010;* ***[6]*** *Gu et al., 2010;* ***[7]*** *Baker & Canessa, 2009;* ***[8]*** *Baker, 2006;* ***[9]*** *Frazelle, 2002.*

Category	Steps Covered
Purpose and Requirements	– Formulate requirements, constraints and objectives[4,5,6,7] – Specify purpose[1,2]
Data Gathering and Analysis	– Aquire data[1,7,8] – Analyze data[3,4, 8] – Forecast expected demand[2]
Functional Specification	– Produce functional specification[1] – Determine inventory levels[2] – Establish unit-load used[7] – High level specification of architecture[4] – Determine operation procedures[2,6,7,9] – Alternative approaches regarding resources and capacity[8] – Class formation of SKUs[2] – Define services and ancillary operations[7,9] – Determine facility location[5]
Technical Specification	– Formulate technical specification[1] – Select means and equipment[1,2,6,7,9] – Calculate capacities and quantities[7]
Development of Layout	– Develop warehouse layout[1,2,3,4,5,6,7] – Sizing and dimensioning of departments[2,6,9] – Determine zones[2,9]
Evaluation and Assessment	– Evaluation[7] – Assessment[7] – Iteration[3,4,5]

Warehouse Layout Design Framework

1 Define Warehouse Objective

Identify warehouse type and prioritize design criteria. Identify the warehouse role in the supply chain network by investigating the material flows in the network. The corporate strategy in terms of product portfolio and expansion plans is investigated.

2 Map warehouse activities

Map warehouse material flow. Identify and observe warehouse activities.

3 Identify storage handling unit(s)

Identify storage handling unit used in the warehouse activities found in step 2.

4 Forecast and analyze expected demand

Find the current demand patterns and future growth scenarios related to the expansion plans investigated in step 1. Analyze how the activities identified in step 2 and the storage handling units in step 3 will be affected by the growth scenarios.

5 Analyze warehouse equipment setup

Analyze automation level, rack system and material handling equipment based on product mix identified in step 1, the storage handling units found in step 3 and expected demand found in step 4. Identify the warehouse equipment setups potential effect on the final solution.

6 Plan space requirements

Determine space requirements for the warehouse activities identified in step 2 based on the growth scenarios developed in step 4 and number of Inventory positions needed in the equipment setups found suitable in step 5.

7 Generate warehouse layouts

Generate layout configurations and analyze their inventory availability, potential honeycombing waste, material flow, flexibility for future expansion/decrease and cost structure.

8 Evaluate generated layouts and identify preferred solution

Ranking the generated layouts in step 7 based on design criteria found in step 1 and thereafter identifying the preferred solution.

Figure 3.1. Visual representation of the warehouse layout design framework.

3.3.1. Step 1: Define Warehouse Objective

The warehouse objective is determined in the initial step to enable a top-down approach and develop an understanding of the warehouse concept and the material flow in the network (Rouwenhorst et al., 2000). The warehouse objective has been developed with a base in the step category "Purpose and Requirements" and with inspiration from Tompkins et al. (2010) and Rouwenhorst et al. (2000) the aim of the step was determined. The aim of the step is to define the warehouse objective and design criteria as well as understand how the corporate strategy affects the network and the warehouse. The warehouse objective is determined by the warehouse type and the main purpose of the warehouse. The design criteria are identified and prioritized to enable decision making in trade off situations in later steps of the framework (Bodner et al., 2002). Product requirements on the warehouse categorized under the functional specification in the frame of reference (Baker & Canessa, 2009). The product requirements are considered here as the product characteristics affect the type of warehouse as well as the role of the warehouse in the network. Key questions and output from this step is shown in table 3.5.

Table 3.5. Key questions and output for the definition of warehouse objective

Key questions	Outputs
• How does the corporate strategy affect the warehouse? • What type of warehouse is it? • What is the warehouse key purpose? • Which are the design criteria of the warehouse and how are they prioritized? • What are the requirements on the warehouse from the products? • In what stage of the product life cycle are the company's products situated?	• Understanding of how the corporate strategy affects the network and by that the warehouse in question • Network map of the material flow to and from the warehouse • Warehouse concept table • Product characteristics identification

To define the warehouse objective it is crucial to identify how the operational strategy derives from the corporate strategy. The current flow and network mapping design are found via order data often with the help of sales representatives for different markets the company is active.

An important aspect to consider from the corporate strategy regards possible market and the placement of production sites and distribution hubs. Ultimately, the question is whether or not an additional investment in the site is the most cost efficient solution within the timeframe specified. To enable alignment of the warehouse design and the future operations it is vital for the warehouse designer to understand how the corporate strategy affects the network. It is suggested that the effects of the strategy are analyzed focusing on the effects on inbound, storage, outbound and ancillary activities. These facts are thereafter used in step 4.

The network map of the warehouse is drawn to understand the environment in which the warehouse is operating and to identify stakeholders to the warehouse. The network map can also visualize the type of warehouse as the material flows in the network are mapped. Requirements or premises for the in- and outbound material flow activities to the warehouse will affect the design criteria and affect what types of services can be expected in the warehouse.

Product requirements are found in product data sheets, which are either internal or external documents of the company. They can also be found in technical specifications available in the warehouse management system or other administrative software used in the warehouse. The product requirements on the warehouse cannot be neglected as the products are the reason that the warehouse exists. Product requirements are often on handling activities; atmosphere regulations and perishability that put constraints on e.g dispatch policies or the real estate.

3.3.2. Step 2: Map Warehouse Activities

Mapping the warehouse activities is important as the material flow will affect the efficiency of the warehouse design. As Twede et al. (2000) state it is an increasing trend to postpone value-adding activities in the supply chain. Not taking this into account can lead to sub optimizations regarding both the warehouse layout and process efficiency which is why an identification of ancillary activities is conducted in connection with the mapping of the warehouse process flow. Determining the overall material flow is a part of the category of functional specification defined in the frame of reference due to the strategic nature of decisions emerging from this step (Rouwenhorst et al., 2010). Key questions and output of this step are shown in table 3.6.

Table 3.6. Key questions and output for mapping of the warehouse activities.

Key questions	**Outputs**
• How does the current material flow look in the warehouse? • Which ancillary operation activities are and should be performed in the warehouse? • How will the material flow in the warehouse be affected by the ancillary operations? • How should the material flow in the warehouse be designed to be aligned with the corporate strategy?	• List of ancillary activities • Process map over the future state of the material handling process

To perform this step observations of the workflow in the current warehouse should be conducted. From the warehouse purpose and operational strategy, ancillary activities can be identified. Mapping of the best possible warehouse process for the purpose is designed. To understand the future demand of space requirements in the warehouse in a later step and to understand how the main process is affected, a list of the ancillary activities in the warehouse should be developed. The list should consider the service requirements in the network, postponement strategies in the operations as well as trends and storage handling units in orders.

To conduct a future state process map for the material handling in the warehouse observations need to be made to map the current situations. It is important to also consider the information flow and capabilities of the current WMS or ERP systems in place. A process map over the future state of the material handling process is constructed to be used as an input parameter to the warehouse layout decisions and facilitate the analysis of how the future demand will affect the warehouse operations.

3.3.3. Step 3: Identify Storage Handling Unit(s)

Identification of the unit load used in the warehouse is conducted to enable better understanding of the technical requirements on the equipment setup as well as the operational processes in the warehouse. Based on the second step, the mapping warehouse activities, the aim of the step is to narrow the scope down to the units handled and identify whether or not the warehouse layout needs to consider different zones for picking or other activities. Finding the storage handling unit used in the warehouse activities is considered as a step in the category of functional specification defined in the frame of reference. Key questions and outputs of this step are shown in table 3.7.

Table 3.7. Key questions and output for finding of storage handling unit.

Key questions	**Outputs**
• What storage handling unit is used in the different processes? • Is there variations in storage handling units, for example different types of pallets? • What is the portion of the storage handling units handled in the processes? • Are different storage handling units ordered together? • Are the load carriers in a return system which requires activities and work process setups?	• Storage handling unit process map • Understanding of how the proportion of orders and units handled is of each storage handling unit • Identification of the need for departments regarding storage handling units

This step is performed by mapping the use of each storage handling unit within the different activities. Observations of the workflow in the warehouse should triangulate the data as well as looking at in- and outbound orders to find the proportions of movements with different storage handling units. Based on the order profiles the movements related to each unit load can be explored and further examined. Sales representatives from the company can also provide useful information on how outbound orders should be collected to suit the customers' expectations.

When considering the storage handling unit in a warehouse it is helpful to use the storage handling unit process map as shown in table 3.8. The map can be used to visualize what storage handling unit is handled in each step of the activities in the warehouse. This will be used as an input to the fifth step.

Table 3.8: Example of storage handling unit process map

	RECEIVING	**PUT-AWAY**	**STORAGE**	**PICKING**	**PACKING**	**SHIPPING**
PALLET	X	X	X			
CARTON		X	X	X	X	X
PIECE				X	X	X
OTHER						X

To understand the proportion of the handling activities effect on each storage handling unit it is beneficial to consider order data of both in- and outbound orders. Analyses that are suggested are for example percentage of orders on storage handling unit. The analysis of the proportions handled of the different storage units and their correlation can help determine whether or not departments are needed to increase operational efficiency.

3.3.4. Step 4: Forecast and Analyze Expected Demand

With a base in the warehouse objective, the warehouse activities and the storage handling unit(s) the forecasting and analysis of the expected demand will tie the first three steps together to understand the future demand on the warehouse. To ensure that the company has a competitive supply chain it is important to have a warehouse which can handle the required demand. It is recommended to develop scenarios that can be used to analyze the sensitivity for the warehouse layout designs which are generated. Key questions and outputs of this step are shown in table 3.9.

Table 3.9. Key questions and output for forecasting and analysis of expected demand.

Key questions	Outputs
• How does the demand profile look today? • What will the demand profile look like for the time frame considered? • How should the scenarios be developed to reflect the potential future operations? • What in the demand profile is likely to change operations in the warehouse in the future?	• Demand profile for the time frame considered • Scenarios to use as sensitivity analysis

The step is performed with both the current demand profile as well as the future demand in mind. To forecast the future operations in the warehouse it is important to consider todays demand, market growth expectations for individual products, as they can affect the warehouse demand differently, as well as the product introduction rate. Also, the growth strategy of the company should be considered since it can affect the in- and outbound material flow. Data is gathered from internal strategic documents, growth expectations, trends in the market and constructed forecasts which is why it can be sensitive and hard to get hold of. Interviews with business controllers, demand planners and sales representatives can be useful to deliver insights to how the demand will look during the time horizon of the warehouse. The rate of new product introductions should be found in the corporate strategy or with the help of the representatives from R&D or sales division of the company.

3.3.5. Step 5: Analyze Warehouse Equipment Setup

With an understanding of the future demands on the warehouse the next step is to find a suitable equipment setup. The equipment setup is here defined as the combination of racks and material handling equipment. In the reviewed literature it is pointed out that they need to be decided together to avoid unnecessary cost and capacity problems (Frazelle, 2002; Rouwenhorst et al., 2000). The aim of this step is to select racks and material handling equipment and determine the appropriate level of automation which is why this step is categorized as a technical specification. Key questions and outputs of this step are shown in table 3.10.

Table 3.10. Key questions and output for analysis of warehouse equipment setup

Key questions	**Outputs**
• What is the current equipment setup, benefits and flaws? • What limitations are set on the rack system by the product requirements and accessibility requirements for the activities in the warehouse? • What level of automation is economically justifiable? • Which is the appropriate lane depth and by which measure should it be calculated? • What equipment will be complementary to the rack system? • What is the cost and the space utilization of the system?	• Identified automation level • Decision table of equipment setup • Space requirements for equipment setup and storage process

To perform this step an in depth understanding of the requirements from the products from step 1 as well as the storage handling units used in each activity from step 3 are used. By using the knowledge from step 4 and the product requirements from step 1, feasible equipment setups are evaluated and selected based on investment cost, handling efficiency, flexibility and their effect on operational cost. The required automation level is found with a base in the throughput of pallets and number of SKU types in the warehouse as proposed in figure 2.10. Flexibility of the warehouse should also be taken into consideration before investing in an automated system as they are often expensive. Technical specifications about warehouse equipment setups can be found at warehouse interior suppliers. Racks are usually procured at supplier and are available in different price ranges and qualities. When selecting the type of racks it is important to consider the dispatching policy of the SKUs, appropriate lane depth and height of the rack system. Trucks and other material handling equipment can often be leased from service providers who also take care of the maintenance of the truck.

Figure 3.2. shows a set of steps for equipment specification as presented by Naish and Baker (2004) to evaluate what equipment setup that should be used. Naish and Baker (2004) argue that with this framework no type of equipment will be overlooked since the narrowing down is gradual through a number of steps. The Naish and Baker-framework's last step is to simulate the equipment setup to assure that the preferred solution is the optimal solution. However, the framework can be used with a different assessment method in a simplified version for manual warehouses if data required for simulation is insufficient.

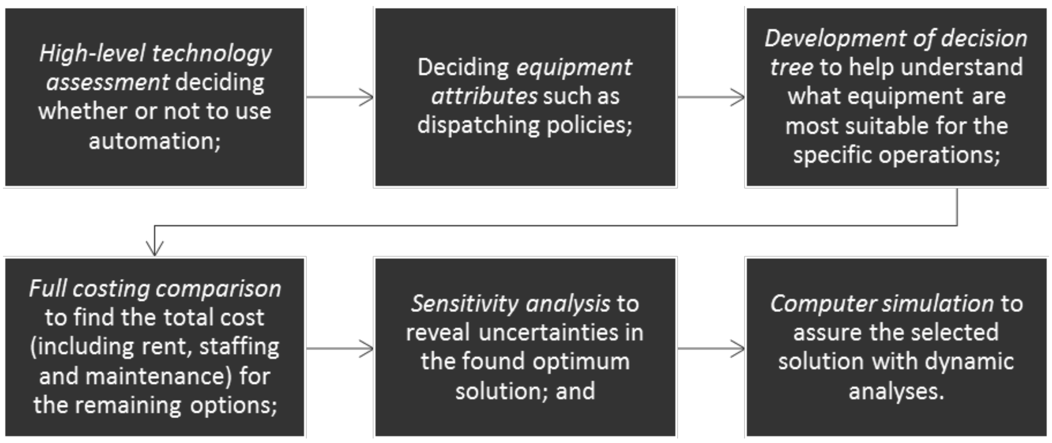


Figure 3.2. Framework for assessing equipment selection in warehousing design (Naish and Baker, 2004)

3.3.6. Step 6: Plan Space Requirements

Planning space requirements is an important step toward aligning the warehouse with the future operations of the company. After the equipment setup has been analyzed a comprehensive analysis of all space required can be calculated. In this step the aim is to determine warehouse space requirements, number of receiving and shipping docks and requirements on equipment. With a base in the previous step, calculations will be conducted on how the processes in the warehouse are affected by the future operations demand. Table 3.11. shows the key questions and output for this step.

Table 3.11. Key questions and output for planning of space requirements.

Key questions	Outputs
• How will the activities in the warehouse be affected by a future change in demand? • How much space will be needed to handle the demand in the different activities?	• Space requirements for the time horizon planned.

Facts needed to estimate future demand, apart from the forecast from the previous step, are a detailed *as is* analysis of the warehouse regarding available pallet positions and activities together with expected operations and processes. The number of pallet positions used today, on average and at peak, is found through the warehouse management system or other administrative registration systems. Using the insights from step 1 the expected change of demand throughout the time horizon is analyzed with regards to how they will affect the warehouse activities space requirements. With the activities found in step 2 the individual space requirements are estimated over the analyzed time frame. Other requirements such as placement or additional equipment that will affect the warehouse layout or design are also identified.

3.3.7. Step 7: Prepare Possible Warehouse Layouts

To be able to prepare possible warehouse layouts primarily step 5 and 6 must have been analyzed. A suitable equipment setup and comprehensive space requirements form the majority of the base for this step. Using the data found in the previous steps a warehouse layout is constructed to support the identified requirements. As the aim of this step is to prepare possible warehouse layouts that are evaluated in the next step, this step is categorized as “development of layout”. Gu et al. (2010) state that redesigning or even rebuilding a warehouse induces high investment costs. For this reason the authors of this thesis believe that the cost of a warehouse design can decrease and that flexibility of a warehouse layout solution can be increased if both the current warehouse layout as well as solutions that enable potential future expansion or downsizing plans are kept in mind. The key questions and outputs of this step are provided in table 3.12.

Table 3.12. Key questions and output for preparation of possible warehouse layout.

Key questions	Outputs
• How does the current warehouse layout look and what are its benefits and flaws? • What is the cost of demounting the current layout? • How are the possibilities of rebuilding or expanding the warehouse? • How large portion of the storage locations should be convenient? • How should the receiving and shipping dock be located? • How should the aisles be configured? • Where should ancillary operations be placed to increase efficiency and facilitate work flow? • How will the activities space requirements change if the future scenario is not fulfilled?	• Division of SKUs into level of convenience on storage location required. • Warehouse layout suggestions

This step is performed by analyzing data from all previous steps. The SKU type popularity is analyzed for an ABC skew of demand to determine the appropriate proportion of convenient storage locations, SKU data can be found via the warehouse management system or other administrative systems used. Additional data needed is blueprints over the current facility and a property map over the location of the company to enable analysis of feasibility of rebuilds and expansion plans. The data can be found at the warehouse administration, property map can sometimes also be found with the government land-surveyor department.

Possible warehouse layouts are proposed by considering the material flow in the warehouse, the proportion of convenient storage locations and space requirements of the different activities. To find a preferred warehouse layout, heuristics and analytical methods can be used. However, they cannot be efficiently used if not sufficient amount of both quantitative and qualitative data are available.

3.3.8. Step 8: Evaluate Generated Layouts and Identify Preferred Solution

The aim of this step is to evaluate layouts and identify the preferred. When evaluating a warehouse layout simulation models are often used in theory while it is not vastly used in practice due to its high complexity and inability to take many alternatives and future demand into consideration (Baker & Canessa, 2009). Instead practitioners often use their own experience and cost models with scenarios to evaluate the investment of a rebuild of a warehouse design (Ashayeri & Gelders, 1985). For this reason investment appraisals are often used as evaluation methods. Table 3.13. shows the key questions and outputs of this step.

Table 3.13. Key questions and output for evaluation of developed layouts.

Key questions	Outputs
• How well does the solution fulfill the decision criteria? • Which is the total cost of the investment, investment cost and operational cost? • How is the material flow efficiency?	• A final solution of warehouse design

According to Baker and Canessa (2009) there are no methods to identify a preferred solution in theory. However, practitioners use cost benefits in business cases or models such as the SWOT-model. The suggested model for identification in this framework is a simple combination of these. By breaking down the decision criteria found in step 1 to measurements, an evaluation table is developed. Finding and gathering performance measures that represents the problems relevant for the project in an accurate way is essential and will determine the quality of the evaluation table. This means that the evaluation model will have different criteria for each warehouse layout design project. It is recommended that as many as possible of the criteria are quantified to facilitate an objective decision. As the nature of warehouse design is complicated and includes many trade-off situations this is hard to accomplish. For this reason quantitative judgements are not forced for all measures as it would only add complexity to the evaluation. In cases where a qualitative judgment gives the grade it is important to elaborate the given grade for decision makers to as great extent as possible. A simple example of an evaluation table is presented in table 3.14. In this example the operational cost has been used to calculate a payback time of the investments in layout 1 and 2 using the outsourcing scenario as a reference. In the example table a five scale (- -, -, 0, +, + +) is used to evaluate the order lead time as it can be difficult to estimate especially if no warehouse management system is in place which can provide detailed data about the daily operations. Rough estimations of whether or not they are likely to increase or not can be made based on analyzing work processes and the equipment's affect on e.g. double handling.

Table 3.14. Example of evaluation model for three prepared layouts

Decision Criterion	Measure	Outsourcing	Layout 1	Layout 2
Minimize operational cost	Double handling cost	675 000 SEK/year	300 000 SEK/year	150 000 SEK/year
Minimize Investment cost	Investment cost	N/A	3 MSEK	5.6 MSEK
	Payback time	0	8	10.7
Maximize space efficiency	Space efficiency (Pallet position per m^2)	N/A	3.4	5.7
Optimal lead time efficiency	Order lead time from the warehouse	+	-	++

3.4. Research Credibility

To keep the research quality high multiple sources should be used. The triangulation of inputs is often mentioned as a major strength in a case study as it simultaneously provides greater possibilities to address a broader range of issues. (Yin, 2003) The strength mostly relies on how the data sources converge to a single conclusion as seen in figure 3.3., (Yin, 2003; Eisenhart, 1989). Views from earlier research might differ or not be complete why there is a need for other data to clarify and ultimately converge. (Voss et al., 2002) Eisenhart (1989) further discuss that the potential for creativity is not only enhanced but the confidence of the research increase as well. Yin (2003) further describes data triangulation as one of four ways for triangulation, the others being: investigator triangulation, theory triangulation and methodological triangulation. The data triangulation mainly covers the use of multiple sources. However, even if the use of multiple resources is good for the research, it also puts a burden on the researcher regarding both time and cost. (Yin, 2003) Triangulation has been considered throughout this study. To the largest extent possible multiple sources have been used to develop, confirm and refine figures and facts from Oatly. Interviews have been triangulated against observations as well as data gathered from ERP systems.

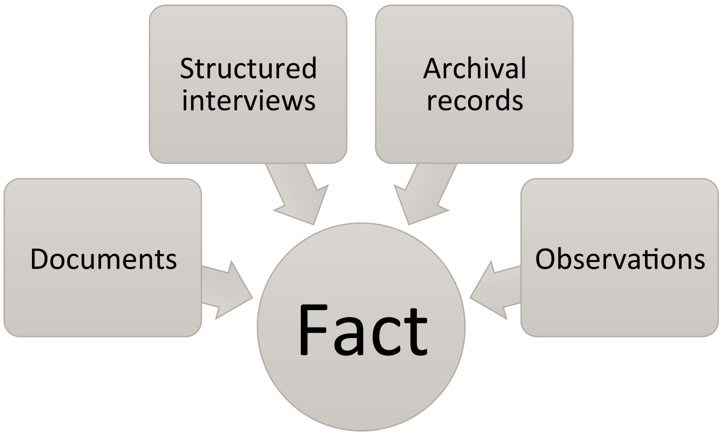


Figure 3.3. Conceptual figure of convergence of evidence based on Yin (2003).

Research credibility is often determined by the validity and reliability of a study (Höst et al., 2011). Voss et al. (2002) conclude that both validity and reliability have a number of dimensions. Validity of a study is concerned with whether or not the study really is about what it appears to be. Reliability is concerned with whether or not the same study can be repeated with the same results.

Validity can be divided into construct validity, internal validity and external validity. Construct validity is to the extent the operational measures has been established correctly for the concepts that are studied. It can be tested by observing whether or not predictions made are confirmed, by using multiple sources of evidence and by seeing if a construct measured can be differentiated from another and by seeking triangulation. Internal validity is determined by the extent to which a causal relationship can be established. (Voss et al., 2002) In this study the construct and internal validity has been closely connected to the trustworthiness of the information collected in the literature study. Yin (2003) has suggested risk mitigation tactics which can be viewed in Table 3.15. The construct validity has been assured as suggested by using multiple sources of evidence in the data collection phase and the manuscript has been reviewed by both the LTH supervisor and interviewees from the case company in several iterations. A chain of evidence has been established with the help of the developed framework and sources of data collection and analysis profiles found in literature. These profiles have also contributed to building patterns and explanations which will mitigate the risk of not assuring internal validity.

Table 3.15. Tactics for ensuring case study credibility (Voss et al., 2002) inspired by Yin (2003). The phase of research connected to the tactic is shown within parenthesis.

Test	Case Study Tactic
Construct validity	Use multiple sources of evidence (Data collection) Establish chain of evidence (Data collection) Have informants review draft case study report (Composition)
Internal validity	Do pattern matching or explanation building or time-series analysis (Data analysis)
External validity	Use replication logic in multiple case studies (Research design)
Reliability	Use study protocol (Data collection) Develop case study database (Data collection)

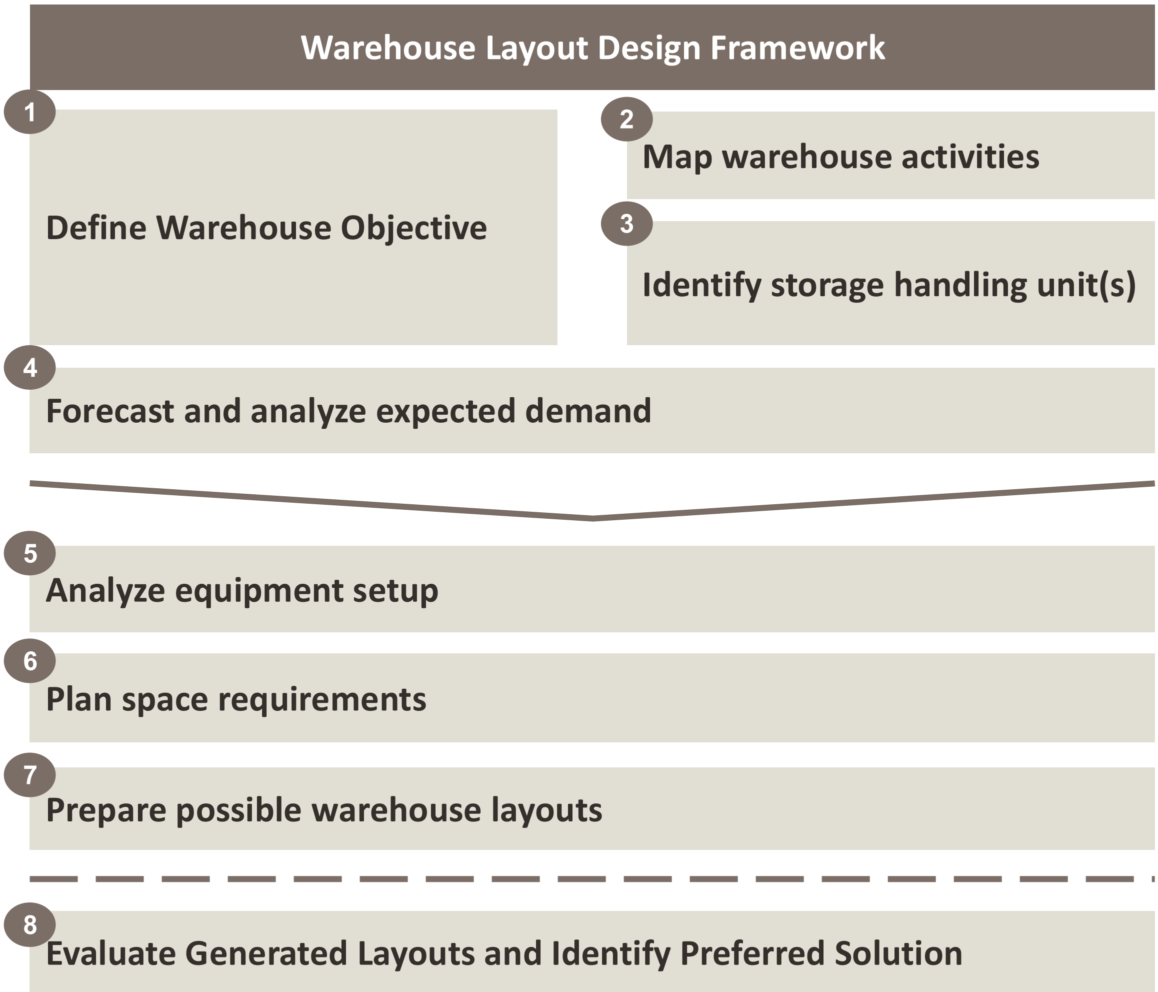
External validity is of particular concern if the study is developing theories that aim towards being generalizable. The external validity concerns whether or not the findings of the study can be generalized beyond the immediate case study. (Voss et al., 2002) As this study is a single case study the generalizability of the results can be questioned. Research performed in one company is usually not enough to make general conclusions. However, as one of the results of the study is a framework primarily based on literature review the generalizability of it as a theoretical framework can be considered. This means that the risk of not having external validity is considerable. As there will only be one case in this study the replication logic can only consist of thorough descriptions of how the case study was conducted. The risk of misinterpretations of literature as well as data collected in the case study by the researchers has been somewhat mitigated by the feedback sessions held with supervisors from LTH as well as in the case company.

Reliability is considered as the extent to which a study can be repeated with the same results and is primarily determined in the data collection phase. (Voss et al., 2002) Reliability in this study is assured by conducting adequate data collection protocols as well as developing a transparent study database that allows for easy access and simple investigation of the study results according to the suggested tactic in Table 3.14. It is important that the researchers conduct the initial part of the research together to ensure a uniform research approach and allows for interpretation reliability to be checked. (Voss et al., 2002) For the literature review, steps suggested by Rowley and Slack (2004) have been followed to keep the reliability and credibility high. For this thesis literature have been searched through research databases, primarily Web of Science, Elsevier and EBSCOhost. The relevance and validity of the articles was evaluated by the journal they were featured in, impact factor, publication date and the number of times the article had been cited. Additional articles have been found through snowballing from the previous articles.

4. Applying the Framework to the Oatly Case

The warehouse design framework has its purpose to help companies facing growth design their warehouse. Due to current strategy and media attention Oatly have recently grown extremely rapidly resulting in operations running close to maximum capacity. The future for Oatly is currently not well defined why a flexible solution is needed to be able to cope with changes in the demand. This chapter will assess the situation at Oatly and provide a solution for an aligned warehouse layout. The warehouse layout design framework is used to assure that no aspects will be overlooked. A simplified version of the framework is visualized in figure 4.1. The Oatly warehouse is described through the steps in the framework. Each step ends with a summarizing table with findings and output from the specific step.

Figure 4.1. Simplified visualization of the warehouse layout design framework.



4.1. Define warehouse objective

To be able to construct a warehouse solution that is aligned with Oatly's future operations a clear definition of the warehouse objective is needed. In this step the warehouse type, key purpose, role of the warehouse and requirements from the products are elaborated. Oatly's current corporate strategy is a differentiation strategy and is therefore introducing new products to their portfolio to win a larger market with innovative dairy substitutes. Oatly is trying to gain market share both from competitive brands in plant-based dairy as well as from the dairy market by, *inter alia,* appealing to end consumers' environmental awareness. Oatly (2015) states that "*our sole purpose as a company is to make it easy for people to turn what they eat and drink into personal moments of healthy joy without recklessly taxing the planet's resources in the process.*" This further strengthens the strategy of being the more sustainable choice. The warehouse is highly affected by the corporate strategy as both the number of articles and the demand is increasing in a very fast pace. Oatly's current strategy has been developed and planned to 2017 which has complicated this thesis as it is looking at a time frame until 2020.

4.1.1. Warehouse Type and Supply Chain Network

The warehouse in Landskrona is a combined production and distribution warehouse, as is common for small companies. Table 4.1 summarizes the warehouse objective. One of the main purposes of the warehouse is according to Oatly to fulfill customer orders which indicates the importance of the distribution activities performed in the warehouse. The second purpose of the warehouse is to store finished products. All Oatly's products need to be held in quarantine for 10 days after production. The need for quarantine can be seen as a part of the production process which underlines the production objective of the warehouse. The design criteria prioritized by the Warehouse Manager and COO at Oatly indicates that operational cost, flexibility and capacity are of a high concern. These criteria are not typically found for production warehouses according to Frazelle (2002) but are in line with criteria for distribution warehouses.

Table 4.1. Oatly's warehouse in Landskrona Objective table

WAREHOUSE TYPE	PURPOSE	DESIGN CRITERIA
PRODUCTION/ DISTRIBUTION	• Fulfil external customer orders • Store finished products • Store raw material • Store work in process (quarantine)	1. Minimize the operational costs 2. Volume and product mix flexibility 3. Warehouse capacity (#available pallet positions)

Oatly's supply chain strategy is currently undefined as is common for small companies in a growing phase. However, the operations at Oatly have traditionally been kept flexible by using external suppliers for both logistics services and production capacity. The decision variable in previous insourcing decisions has been cost efficiency which further underlines the priority of the design criteria for the warehouse. Before Oatly built the warehouse in Landskrona 2013 they stored their products at a 3PL provider nearby. To supply the market in UK Oatly has contracted warehouse services in Manchester. Products which are subcontracted to external producers require types of packages which the Landskrona production site currently does not have the packaging equipment for. As the site in Landskrona is planned to be expanded, new packaging machines will be introduced which can lead to that Oatly will bring back production in-house of some currently subcontracted products. This has not been investigated in this study. The site in Landskrona has a maximum production capacity of 50 million liters related to the capacity of the sewage plant in the county. If Oatly expands the production they must contribute to an additional investment in the sewage plant. The additional investment would then yield a maximum capacity of 80 million liters. To produce beyond 80 million liters Oatly will need additional subcontractors in another county or to invest in another plant placed in another geographical location. For this reason the volume 80 million liters is the maximum capacity considered for the Oatly warehouse in Landskrona.

Approximately 95 % of Oatly's product flow currently goes through the warehouse in Landskrona. The remaining flow go directly from subcontractor to the next actor, mainly to the warehouse in the UK. The product network flow is shown in figure 4.2. From the production site in Landskrona, approximately 200 m from the warehouse, palletized finished products are transported with a trailer. In the future expansion plans for the Landskrona site a proposal is to move the palletizing activity to the warehouse and have the trays of finished products move automatically on a conveyor to the warehouse. Subcontractors send lorries to the warehouse every week. In several geographical markets where Oatly are active, the food retail business has a few food retail chains that dominate the market. This means that the food retail chains are powerful in the supply chain network and can put pressure on food producers. About 43 % of Oatly's sales are through the food retail chains in Sweden, making this market the most important customer base for Oatly. In Oatly's case this has led to that they have been forced to produce oat drinks for the retail chains own brands to be able to sell their own products through their sales channels. The food retail chain's powerful position in the network has also led to that their transports and orders are set to optimize their own warehouses which leads to additional work for Oatly as they need to process and handle orders more frequently. Oatly tries to sell products directly to their customers to reduce the power position of wholesalers where possible.

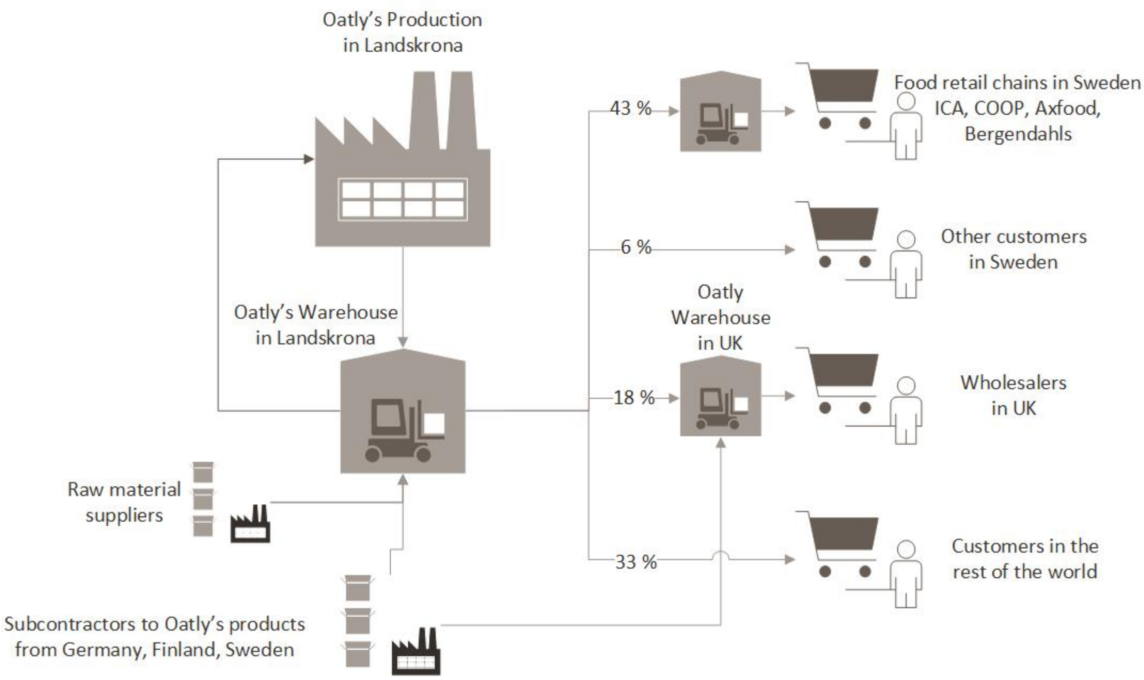


Figure 4.2. Oatly's supply chain network

4.1.2. Product Portfolio and Requirements from the Products

The Oatly product portfolio consists of fresh and ambient oat drinks, oatgurts, cooking bases and on-the-go drinks. Parts of the product portfolio are shown in figure 4.3. Ice cream is also a part of the portfolio however, not considered since its flow is not through the Oatly warehouse as the warehouse does not handle frozen goods. All products are perishable and have lifetime from 4 weeks up to a year. The products with the longest lifetime are the oat drinks that can be stored in an ambient temperature. These drinks come both flavored and unflavored in 1L and 0.25L carton packages, some of which for both Oatly and other private labels such as ICA and Garant. These products are under consideration for outsourcing when the capacity of the warehouse will be reached. Additionally, due to the long shelf life the products can be shipped to other markets such as Spain, the UK and Germany. The ambient products are the ones sold in largest quantities. To gain a larger market share Oatly sells their products through the chilled department at the food retail chains in the Nordic markets. For this reason the oat drinks that can be stored in an ambient temperature is declared as chilled food thus require an unbroken chilled supply chain even though it is not necessary for the quality of these products. The rest of the products require a chilled environment to ensure top quality. Fresh oat drinks come as both flavored and unflavored and are sold in in 1L carton packages and flavored packaged in 0.275L resealable PET-bottles. The oatgurts and parts of the cooking bases are produced in Landskrona and are distributed in carton packages. The rest of the cooking bases are sold in 0.2l and 0.5l beakers and are currently produced by a subcontractor in Finland. The on-the-go range consists of a smoothie packaged in 0.25L glass bottles. All products are not sold in all markets. The chilled products are mainly sold in Sweden but are available in Scandinavia. Approximately 50 % of the products are chilled in today's operations.

Figure 4.3. Parts of the Oatly product portfolio. From the left the 1L fresh oat drink, 1L colonial oat drink, 0.25L flavored oat drink, 0.2L beaker for fraiche, 0.275L plastic bottle and 0.25L glass bottle. Source: Oatly.com (2015)

The primary requirement from the product is the temperature. Oatly's experience show that outsourcing logistics functions for a chilled supply chain is complex and hard to handle from a distance. Ambient products are subject to considerations for outsourcing warehousing services as they have a longer shelf life and are more durable. Especially for material flows that potentially could make the material flows in the network more effective, as reducing length of last step transportations or double handling. For this reason it is primarily export and storing of private label products that are considered for outsourcing.

The packaged products are heavy and somewhat fragile which affect the material handling equipment as well as the equipment setup selection in the warehouse. Even though the time to perishability is long compared to substitutes like dairy products, Oatly's customers demand a long shelf life on the products. For this reason the products are dispatched as soon as possible according to a FIFO policy. This further complicates the equipment setup selection.

Oatly's products are hard to identify according to the Fisher matrix. Using Lee's (2002) characterizations for supply and demand uncertainty the supply chain strategy should be either efficient or responsive depending on how demand and the characteristics of the products are analyzed. The supply uncertainty is low as the production is stable and the process is well-developed and dependable which can be seen in table 4.2. The two characterizations that deviate from the trend are that Oatly has a limited amount of supply sources of the products and that there can in short term be a potential capacity constraint in the production. The character of the demand uncertainty is harder to identify. All characteristics referring to forecasting or variations in demand can be applicable at Oatly. The uncertainties are not on a weekly basis, rather in a monthly perspective. Comparing Oatly's products to substitutes like dairy products the demand uncertainties are high. However, comparing to products in other markets like fashion apparel or high-end technology the demand can be considered stable.

Table 4.2. Supply and demand characteristics at Oatly. Supply characteristics in bold are the stable supply, otherwise evolving. Demand characteristics in bold are typical for functional products, otherwise innovative.

Supply Characteristics	**Demand Characteristics**
Less breakdowns	High demand uncertainties
Stable and higher yields	**More predictable demand**
Less quality problems	Variable demand
Limited supply sources	**Long product life**
Reliable suppliers	**Low inventory cost**
Less process changes	High profit margins
Potential capacity constraints	High product variety
Easier to changeover	**Higher volumes per SKU**
Flexible	**Low stockout cost**
Dependable lead time	**Low obsolescence**

Lee (2002) concludes that it is common that food industries have a fairly certain demand which leads to that the market is often placed in the quadrant for efficient supply chain. For this reason the result of the analysis of Oatly's products are that they are functional which can be seen in figure 4.4. Having an efficient supply chain affects the design criteria of a warehouse to be more focused on both lowering costs and increasing utilization thus further underlining the decision criteria of the Oatly warehouse.

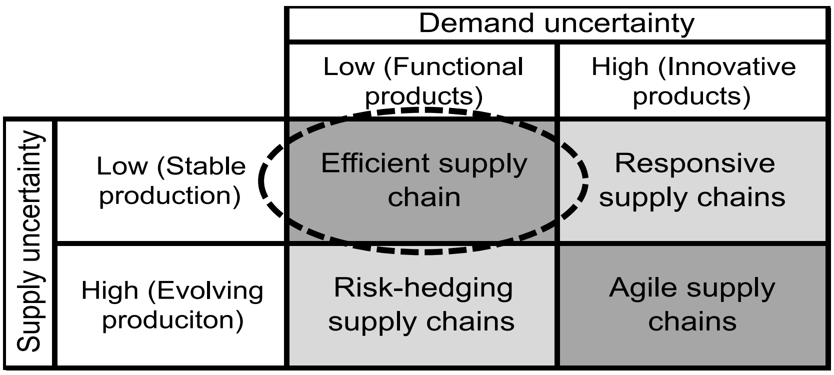


Figure 4.4. Oatly's placement in the supply and demand uncertainty matrix based on Lee (2002)

Summary of Warehouse Objective	
Findings	• Combined production and distribution warehouse • Partly subcontracted production which might be taken back in-house with product expansion • Little power compared to large customers • Varying product portfolio regarding perishability and packaging
Output	• Need for both an efficient and partly flexible supply chain • Warehouse must be able to hold inventory • Warehouse must be able to consolidate and ship accurately • Focus on efficient supply chain and low costs • Ability to outsource for some markets

4.2. Mapping of Activities in the Oatly Warehouse

With its base in the warehousing process found in literature the Oatly warehouse has been mapped. These activities will be further elaborated for the Oatly case in this section. Figure 4.5. shows a sketch adapted from Tompkins et al. (2010) over the activities in the Oatly warehouse. The process mapping showed that unnecessary double handling in the warehouse is mainly induced during the receiving, to reduce honeycombing in storage, shipping and the ancillary activities, especially laboratory tests, currently conducted in the warehouse. The laboratory tests are necessary but non-value adding while the movements to reduce honeycombing is a non-value adding movement for the pallet which is why it should be reduced. The main change in the activity landscape for the future operations in the warehouse is the plan to move the pallet mounting station into the warehouse from the production facility. This move would facilitate a more even flow for the receiving activity compared to the current truckloads.

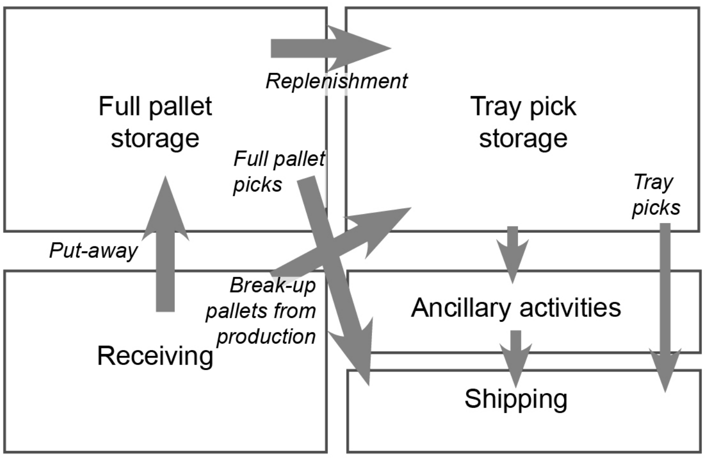


Figure 4.5. Sketch over the process flow within the Oatly warehouse inspired and adapted from Tompkins et al. (2010).

A sketch over the Landskrona warehouse is shown in figure 4.6. The warehouse is firstly divided in a refrigerated and an ambient part and secondly between single-deep storage racks and deep storage racks. The deep storage racks, called maxi-packers, are in the refrigerated area 35-deep and 21-deep in the ambient part. The 35-deep maxi-packer accounts for 1715 pallet positions whereas it account for 2184 in the ambient zone. The remaining 600 pallet positions are found in the single-deep racks. In the maxi-packer an automatic pallet mover is used to move pallets into the lane as far down as possible. The rack system ensures a FIFO dispatching policy which is a requirement for the perishable goods handled. To efficiently use the rack system it is not possible to store different articles in the same lane thus resulting in honeycombing waste. As a result the warehouse must be considered full even when there are free pallet positions in the warehouse. To avoid honeycombing waste the workers in the warehouse move pallets from the maxi-packer to single-deep racks when the amount of pallets in a lane is low which results in that approximately 8 % of the pallets are double handled. Apart from full pallet storage the bottom shelf in one aisle is reserved for broken pallets where tray-picks are conducted.

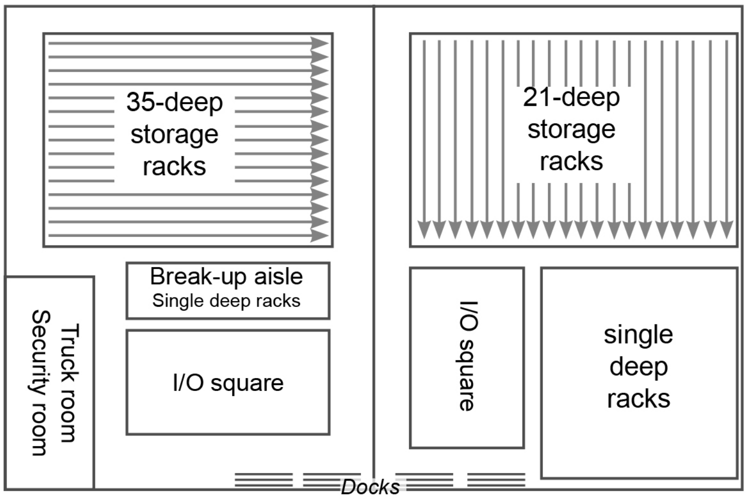


Figure 4.6. Sketch over the Oatly warehouse.

A flowchart of activities performed in the Oatly warehouse is shown in figure 4.7. The main activities in the warehouse are receiving, put-away, storage, picking and shipping. Apart from these, the ancillary activities repacking to expo pallets and laboratory identification are also performed. The warehouse receives all their goods via truck through the shipping and receiving docks. The products produced in Landskrona are packed in full pallet loads and placed in a lorry, which is fetched by a warehouse employee whenever it is full. Subcontractors' products are shipped to Landskrona by lorry. When the lorry arrives to the warehouse the driver registers in the warehouse office and is allocated to a dock. The pallets are then moved out of the lorry with a pallet truck into the warehouse. When receiving goods the pallets should be placed on the inbound/outbound square (I/O square) to offload the lorry as quickly as possible. However, this is not always the case since the I/O square often is full with ready-to-ship orders that are awaiting pick-up. For this reason received pallets are placed in the aisles to await put-away. To avoid the extra handling from having the lorry transport between the Landskrona production and warehouse, Oatly plans to install an automated transport line. This would result in a continuous flow to the warehouse of either pallets or trays which would both alleviate the docks as well as smoothen the workflow for the warehouse. This kind of automatic system would affect the structure and layout in the warehouse and the work processes. As Oatly plans to expand the production site in Landskrona the portion of the total flow and the inflow can increase through this channel.

The pallet loads produced in Landskrona receive their identity in the last step of the production line. This means that the pallets can be put directly to their designated location upon arrival in the warehouse. The pallets are moved out of the trailer with a pallet lifter and set down on the I/O square. The label is then scanned and put-away is conducted with a reach truck. Depending on the pallet location the first thing is to move the automated pallet mover to the right lane/slot and thereafter put the pallet in the right slot. When production runs a batch the produced volume does not come out as an even number of pallet loads resulting in that the last pallet is not full. These broken pallets are often placed directly in a break-up aisle for tray picking. However, if there is no broken pallet available in the break-up aisle with each article a new pallet is picked from the pallet reserve area and placed to break-up.

As the products are sensitive to bacteria the quality of the products and primarily the production need to be high. As a consequence, the products are held in quarantine for 10 days. During the quarantine, tests might have to be done. If a test indicates a risk further tests needs to be conducted on individual pallets. It is extremely important that the right pallet is picked. This means that pallets that are in storage can be subject to investigation and need to be accessible for tests. It should be pointed out that for laboratory tests the pallet can be moved several times to access the specific pallet that is needed. A pallet under investigation needs a location to be placed in while it is under investigation and is currently placed on the I/O square, where it blocks space needed for receiving and shipping, or in aisles.

Apart from the finished goods, the warehouse also stores raw material, material for marketing purposes and material and product tests for the product development department. The raw material handled in the warehouse will not be considered in this study as the plan is to move these to the production facility to minimize double handling and free space in the warehouse. Raw material, which require a chilled environment as well as being flammable, will not be moved due to safety regulations. In the future, raw material will be moved from the warehouse to a production warehouse with direct connection to the production facility. However, marketing material and material for product development will increase in the future and occupy more space than today.

One of the private label companies requires that the products sent are placed on expo-pallets. The expo-pallets are built manually as the packaging machine packs the pallets automatically in a pre-programmed pattern. A pallet that comes from production is dismounted and the primary packages are instead put on a half-pallet with tiers separated by a sheet of cardboard. The pallet is then stabilized with special corner pieces and wrapped in shrink-wrap. Thereafter two half-pallets are put on a EUR-pallet and shrink-wrapped before it is put back to storage. If the material flow for the private label is outsourced the repacking activity would be outsourced with it.

The picking is conducted in the warehouse both as full pallet picks and tray picks. Full pallet picks are conducted with a reach truck and is scanned and registered for the order. Break-up picks are conducted with a pallet truck that is rolled manually as the trays are placed on a pallet on a pallet lifter moved by the picker. One should point out that picks are not exclusively made for orders but for internal movements as well. The internal movements are mainly to increase the storage efficiency and utilize the space better. This double handling is shown as dotted lines in figure 4.7. This results in double handling of pallets which incurs extra operational costs in the warehouse. During the 30 day period approximately 8.5 % of all pallets were registered on more than one pallet position yielding 573 pallets and 593 non-value adding moves, see table 4.3. As shown in table 4.4, the double handling correspond to approximately SEK 177 000/year as the time it takes to move one pallet have been approximated to 5 minutes including both administration and the physical moving of the and employee costs of SEK 300/hour.

Table 4.3. Number of individual pallets that have been moved 1, 2, 3 or 4 times to reduce honeycombing

Number of pallet positions registered	Number of pallets	Percent	Number of non-value adding moves
1	6178	91.51 %	0
2	549	8.13 %	549
3	22	0.33 %	44
4	2	0.03 %	6
Total	6751	100 %	593

Table 4.4. Approximate double handling cost per year

Layout Suggestion	Double handling	Double handling cost
Keeping maxi-packers	49 h/month	177 900 SEK/year

Packing is conducted with the break-up picking orders and consists of wrapping pallets in shrink film. This is conducted in a packing station near the docks. After the picking, and eventual packing, the pallets within each order are placed on the I/O square in a lane. The lanes have space for 10 pallets each and there are 14 lanes. As the I/O square is shared for both receiving and shipping of the pallets, on high pressure weekdays the orders fill the I/O square and pallets are placed in aisles before the lorries arrive.

Summary of Activities in the Oatly warehouse	
Findings	• Storing of finished products, raw material, marketing material and material for product development • Storing in the Oatly warehouse is in maxi-packers and single-deep racks • Picking is conducted with both tray and full pallet loads • Pick for order and for relocation of pallets • Ancillary activities are present: Laboratory tests, repacking
Output	• Space must be allocated to ancillary activities • Accessibility to pallets when testing is preferred • High utilization of the I/O square, which leads to congestion • Picking should be minimized to only be conducted for order

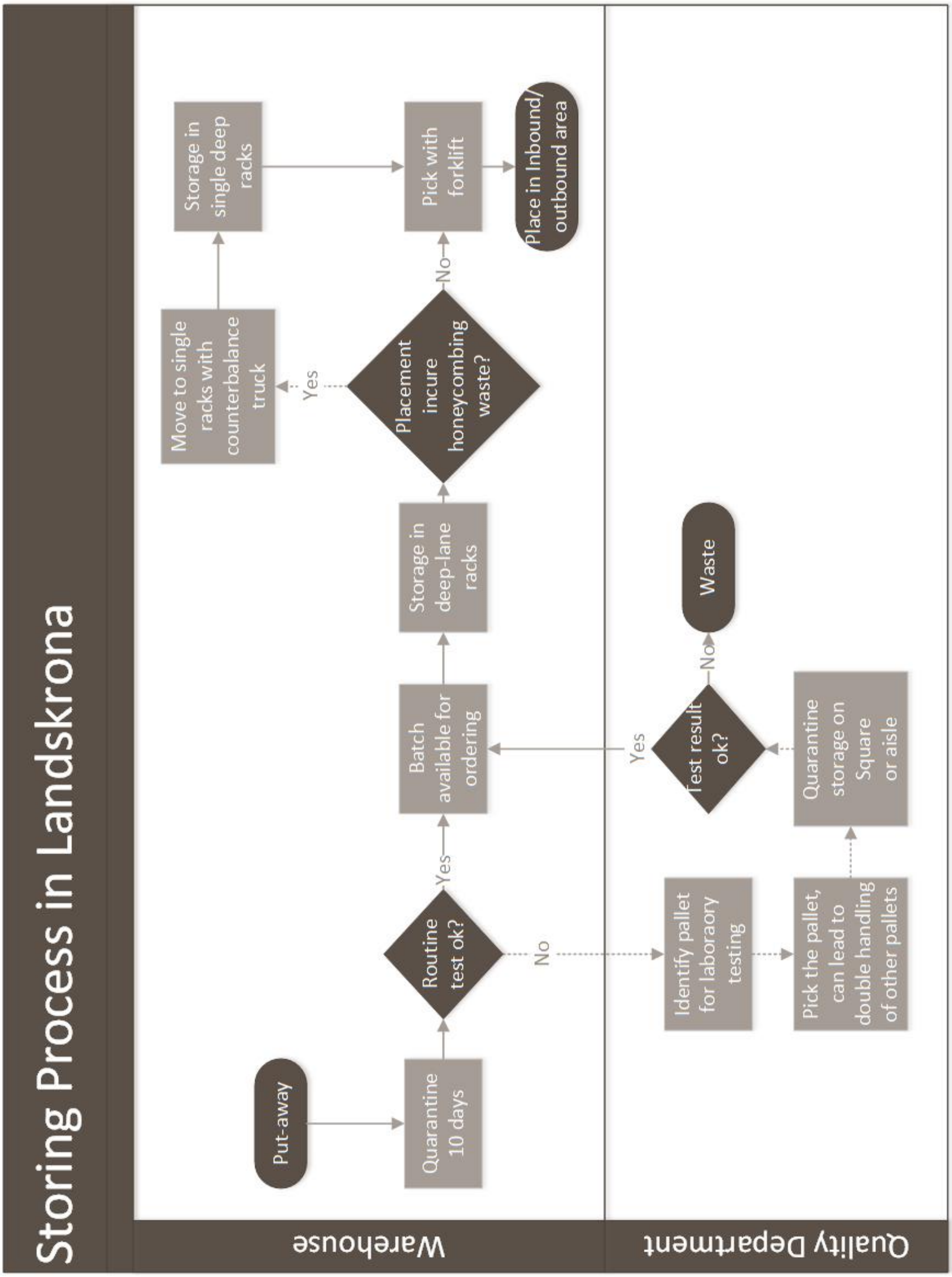


Figure 4.7. Warehouse process at Oatly

4.3. Storage Handling Units Used in the Oatly Warehouse

In this step the storage handling units used in the Oatly warehouse is identified and discussed. The warehouse in Landskrona primarily handles pallets, both in the flow to and from the warehouse. For this reason the warehouse in Landskrona can to a large extent be seen as a unit load warehouse. The outflow consists of both full pallets and break-up pallets. The storage handling units used for each activity in the warehouse are mapped and shown in table 4.5. As can be seen, pallets are the main carrier throughout the activities with the exception for picking of trays. However, trays are immediately put on a pallet for final packing and shipping.

Table 4.5. Mapping of storage handling unit currently used in the activities within the warehouse process

Storage handling unit	Receiving (LKR Production)	Receiving (External Production)	Put-away	Storage	Picking	Packing	Shipping
Pallet	X	X	X	X	X	X	X
Half-pallet							
Tray					X		
Piece							

Units used regarding the ancillary activities within the warehouse have a wider spread as shown in table 4.6. When repacking to expo-pallets an ordinary pallet to expo-pallet the full pallet must first be dismounted only to be built again. This means that all units are handled due to the packing from production. One of the largest food retail chains in Sweden are requesting half-pallets for expo-pallets. These are however put on a EUR-pallet for shipping thus making the picking and shipping more efficient. For the laboratory testing there is a requirement to be able to make tests on single pieces why all larger units need to be handled. For marketing purposes the unit varies from full pallets to trays. Though, marketing also requests other goods to be held in the warehouse such as banners and bicycles why there is a need to be able to handle bulky goods. For the product developers all of the handling units must be able to be handled.

Table 4.6. Mapping of storage handling unit currently used in the ancillary activities

Storage handling unit	Re-packing	Laboratory testing	Marketing activities	Product development
Pallet	X	X	X	X
Half-pallet	X			
Tray	X	X	X	X
Piece	X	X		X

Pallets are the main load carrier in the Oatly warehouse. However, they are not always filled with full loads of one article but are mixed in break-up as well. Based on figures from sales orders, the proportion of the storage handling units used for shipping is according to figure 4.8. Many orders only consist of full pallets and are mainly for the larger food retail chains that have the capacity to handle large amounts. Almost one fourth of the orders solely contain break-up pallets which is a result from sending many product samples. However, most of the orders contain both full pallets and break-up pallets. These figures are assumed to remain unchanged in the future.

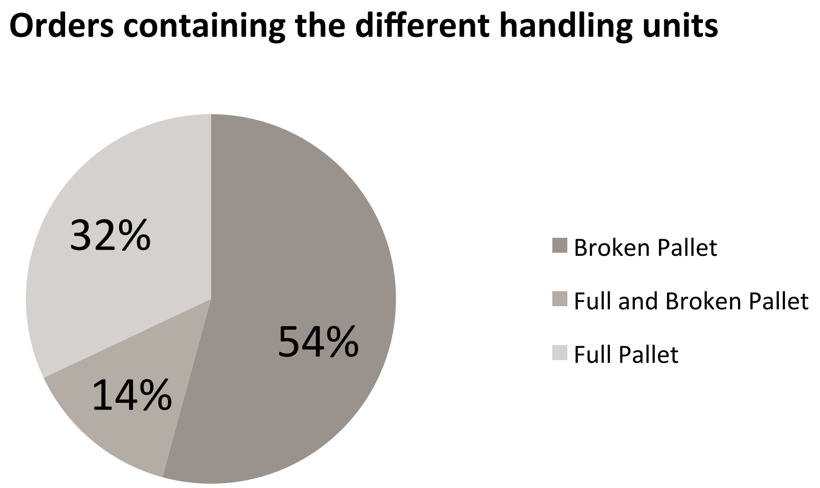


Figure 4.8. Percentage of orders containing either full pallets or broken pallets.

The pallets used are EUR-pallets and CHEP-pallets. The EUR-pallets are the main carriers that are shipped to the customers all over the world while the CHEP-pallets are only sent to the UK. In the warehouse the CHEP-pallets have 204 dedicated positions (4 % of total pallet positions). The warehouse also handles half-pallets. These do not affect the handling and storage as they are placed in pairs on a EUR-pallet. If the material flow for the export is outsourced the handling of chep pallet are outsourced too.

The EUR-pallets are in a return system with the transport providers. The number of pallets picked up is registered to an account. To balance the pallet accounts Oatly's external transport providers leave the registered number of empty EUR-pallets whenever possible for their routing. The pallets are then used in the production. Due to hygienic reasons and the wide spread usage at the Swedish food retail chains plastic pallets might be introduced. Introducing the plastic pallets would incur another return system to be handled which has different actors than the EUR-pallet return system. An introduction of a new type of pallet would also add to the complication of the picking and packing activities. The use of plastic pallets would introduce an additional number of SKUs in the warehouse as the customer would be able to choose whether to order plastic or wooden pallets. To decrease the complicating effects of the introduction of plastic pallets a pallet tilter/shifter could be installed. As it would make the pallet choice more flexible it would make the warehouse able to cope with the demands on different pallet types in a more satisfying way. Today the food retail chains make up 43 % of the total orders and are the target for the plastic pallets.

Summary of Storage handling unit(s) used in the Oatly Warehouse	
Findings	• Primary usage of pallets in the in- and outflow • Trays are picked frequently most frequently • Half-pallets are handled on EUR-pallets in the private label flow • Ancillary activities demand access to all handling units
Output	• Warehouse alignment towards pallet handling • Allocate area for tray picking which is in line with the number or articles • Allocate area for marketing and product development which can handle different types of storage handling units

4.4. Forecast and analyze expected demand

In this step the expected demand for the next five-year period has been explored. The outputs of this step will be presented in two sections, one that answers the questions of how the demand looks today and one that explores the demand profile in five years through three scenarios. The proportions and trends found in today's demand profile are applied to the future scenarios to forecast the effects of the future demand, if nothing else is stated.

4.4.1. Current Demand Profile at the Landskrona Warehouse

The inflow of products is stable and directly connected to the production both in Landskrona and from subcontractors. Both of these order inflows are predictable. The incoming warehouse flow from the production in Landskrona is dependent on which product type is produced. The production rate in Landskrona is one pallet every six minutes throughout the production hours. This yields approximately 5 truckloads of 30 pallets from the production per day. When the expansions in the production site are made the production pace will approximately double. Each subcontractor send a truckload approximately once a week except for the subcontractor in Germany that sends seven truckloads per week and the Finnish subcontractor that send one truckload per month. On average the warehouse receives 11 truckloads per week from subcontractors.

The number of outgoing customer orders are approximately twice as high as the number of incoming orders. The customer orders have seasonality on a yearly basis where the sales go down in the summer and around New Year, the sales trend lines as can be seen in figure 4.9. This trend for Oatly's sales has been apparent since launch. The trend and has remained stable but has moved up each year to a higher level since 2009. During the last years the average number of pallets in storage has increased in line with the increased rate of production. The stable inflow from production and the yearly seasonality in demand results in a fairly stable storage level with yearly peak in the end of the summer and around New Year as shown in figure 4.10.

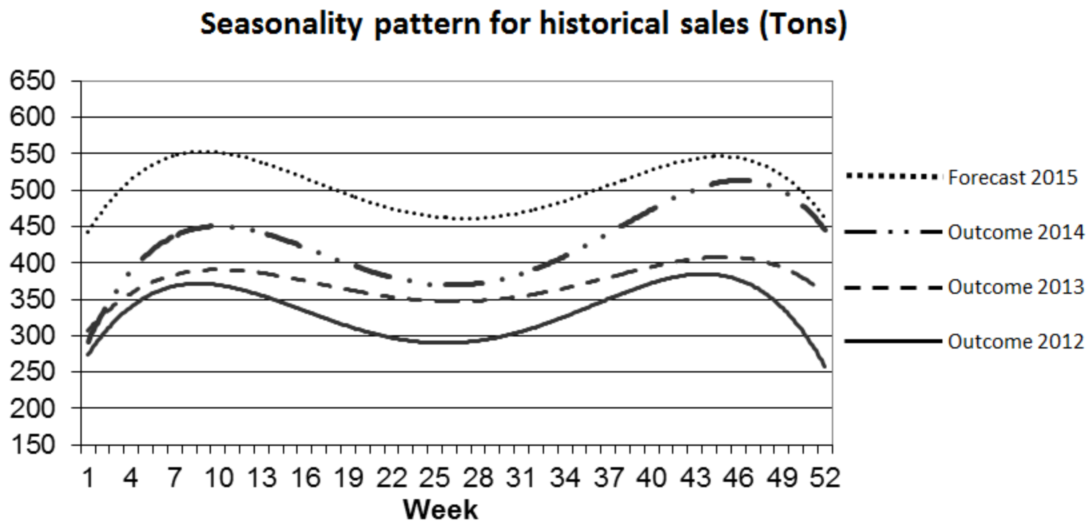


Figure 4.9. Seasonality pattern for historical sales (Tons)

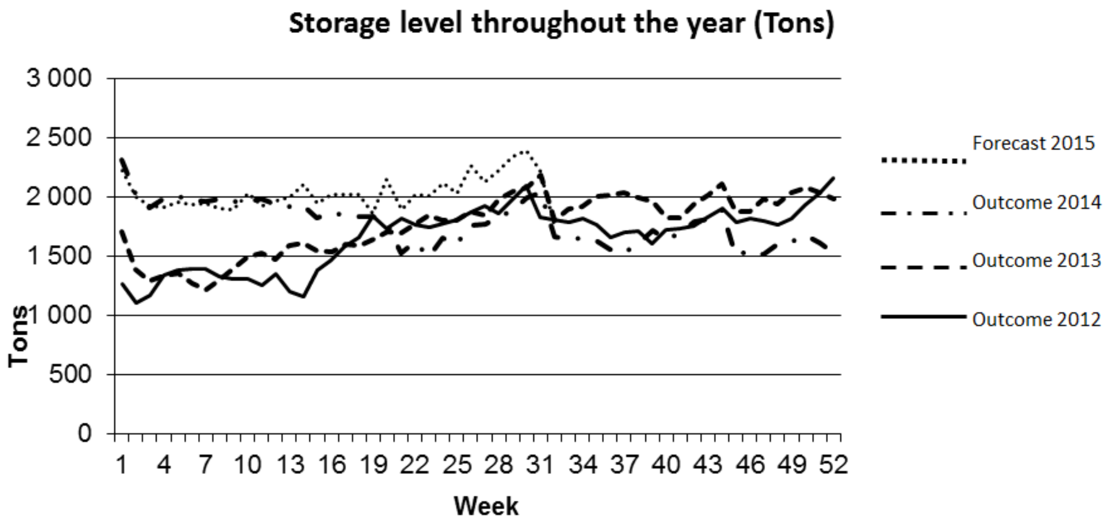


Figure 4.10. Storage level throughout the year (Tons)

The peak-to-average ratio in the warehouse for the yearly seasonality is fairly low. The peak-to-average has decreased during the last years and is expected to decrease during 2015, see table 4.7. The peak-to-average ratio is below 1.5 and is fairly stable. This means that the warehouse should be dimensioned to be able to handle the peak number of pallets expected.

Table 4.7. Peak-to-average ratio on stored pallets from 2012

Year	Peak of the year (tons)	Average (tons)	Peak-to-average ratio
Outcome 2012	2157	1651	1.31
Outcome 2013	2310	1773	1.30
Outcome 2014	2180	1760	1.24
Forecast 2015	2385	2033	1.17

The customer orders have a distinct pattern over the week. The largest numbers of orders arrive on Mondays, seen in figure 4.11. The number of pallets ordered on Mondays are proportionally larger than the number of orders on Mondays which means that orders are usually bigger on Mondays. Storage builds up during the slowest day, Wednesday, and is shipped out on Mondays. As a result the number of pallets in storage peaks during the end of the week which can be seen in figure 4.12.

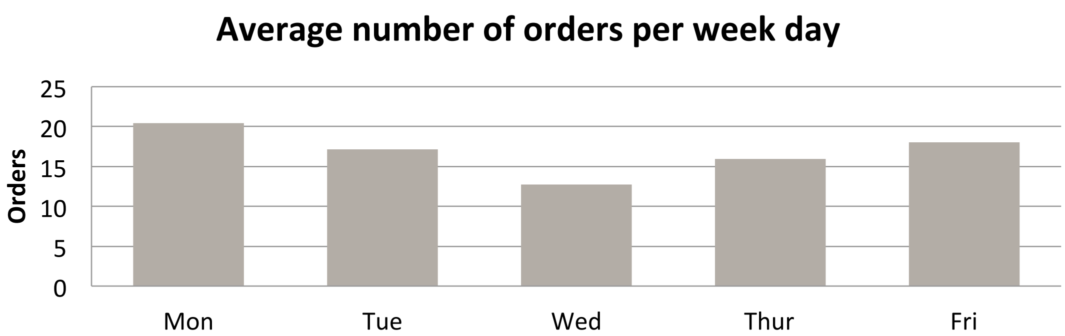


Figure 4.11. Average number of orders per weekday

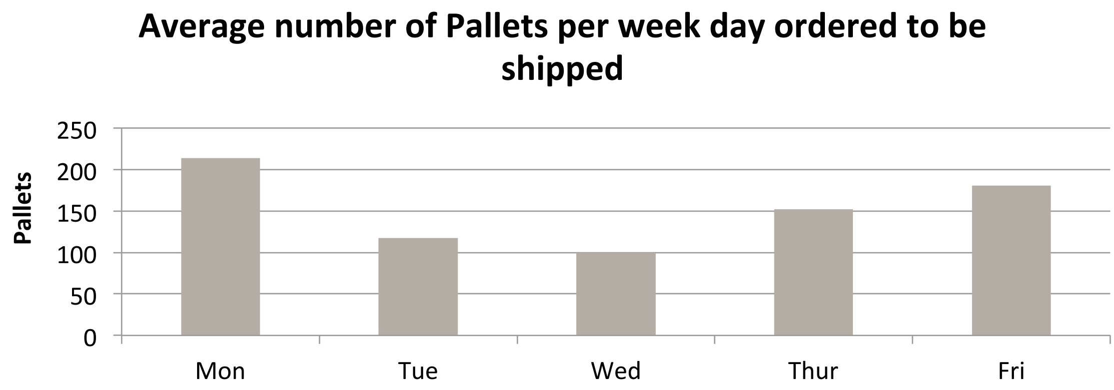


Figure 4.12. Average total number of pallets ordered per weekday

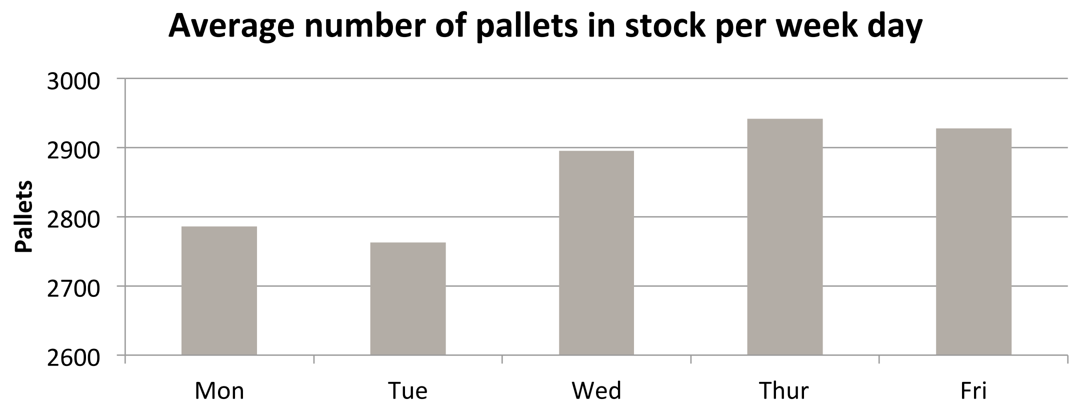


Figure 4.13. Average number of pallets in stock per weekday

The weekly peak-to-average ratio for the number of orders and pallets per weekday is shown in table 4.8. The ratios are over 2 which means that ensuring that the warehouse have capacity for the peak can yield unnecessary costs due to over capacity (Frazelle, 2002). However, not having an alternative plan for the additional pallets ordered will yield additional costs in disrupted operations, congestion and safety risks as pallets are likely to be put in aisles. To forecast the future number of orders and pallets that the capacity needs to cover will therefore instead be based on the distribution of average number of orders per weekday shown in figure 4.12. To be able to handle all pallets ordered on peak-days solutions like turnover time on the square will be further explored in step 6.

Table 4.8. Peak-to-average ratios for weekday orders

Weekly peak to averages	Average	Peak	Peak-to-average
Orders per weekday	16	33	2.02
Pallets per weekday	147	369	2.51

The average number of pallets per order in 2014 was 6.3 pallets. The distribution of number of pallets in per order together with an accumulative line can be seen in figure 4.14. To a large extent the customer orders from the Landskrona warehouse are small. Approximately half of the orders are three pallets or fewer and 80 % are 11 pallets or fewer. The distribution peaks at one pallet per order which is due to a large amount of product samples sent out from the warehouse as well as broken pallet orders. The next peak is at 15 pallets per order. The reason for this peak has not been investigated further. The next peaks are spikes at 26 and 30 pallets per order. A full truckload of EUR-pallets is by standard 30 pallets the same number for CHEP-pallets is 26 pallets which explains these peaks. Most of the full truckload orders are said to be shipped abroad foremost to the warehouse in the UK and often consist of more than one product type.

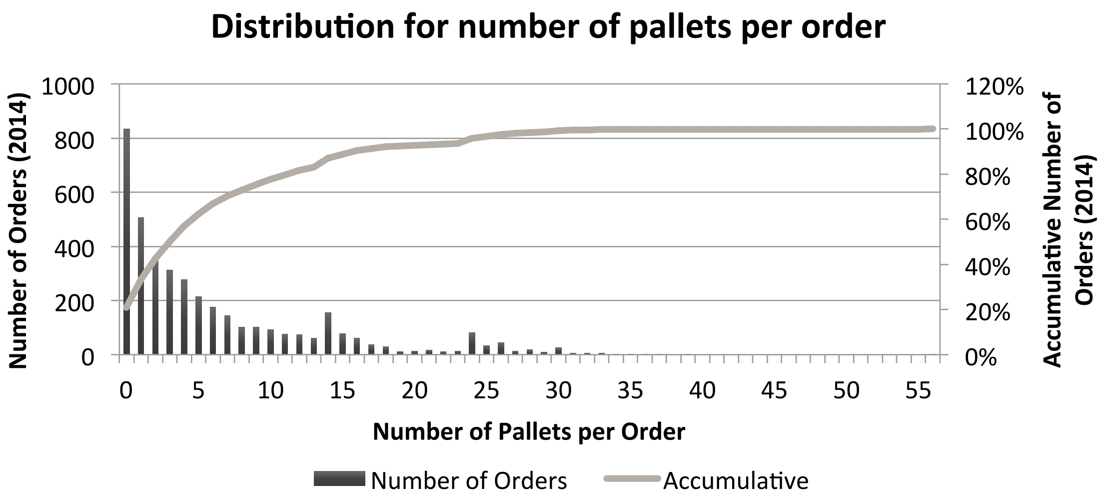


Figure 4.14. Distribution of number of pallets per order based on sales during 2014. "0" represents broken pallets only.

Further, the number of order lines per order can be visualized as in figure 4.15. For most orders every line include a different SKU why approximations regarding the total number of SKUs per order can be made. On average an order includes 4.4 different articles where 80 % of the orders include six articles or less. For the specific order line the distribution for number of pallets is shown in figure 4.16. It is evident that there are mostly broken pallets being demanded. Over half of the order lines are less-than-pallet, shown as *"0"* in figure 4.16. The average amount per order line is 1.4 pallets with 90% of the order lines including 2 pallets or fewer.

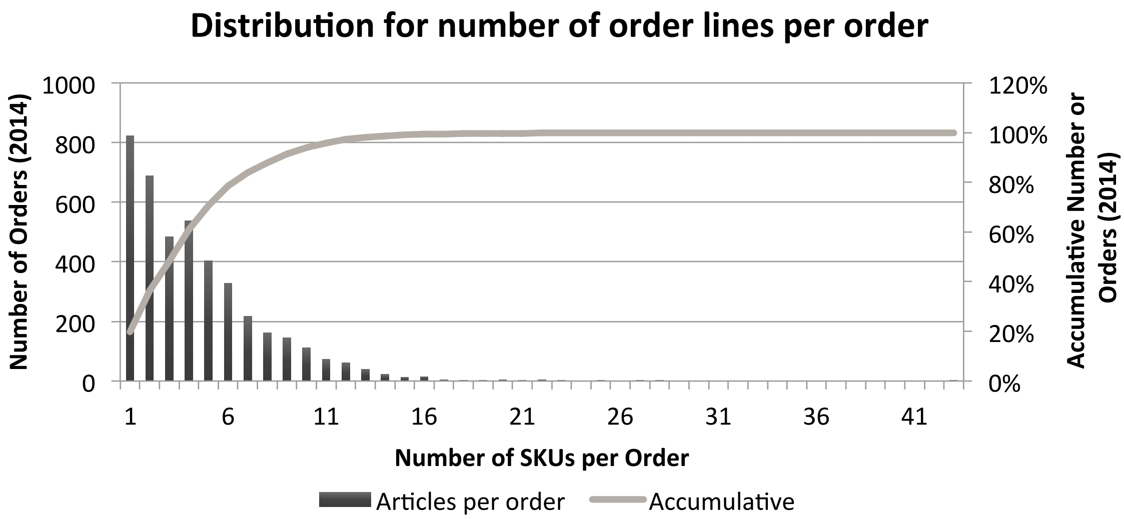


Figure 4.15. Number of different articles per order based on sales during 2014.

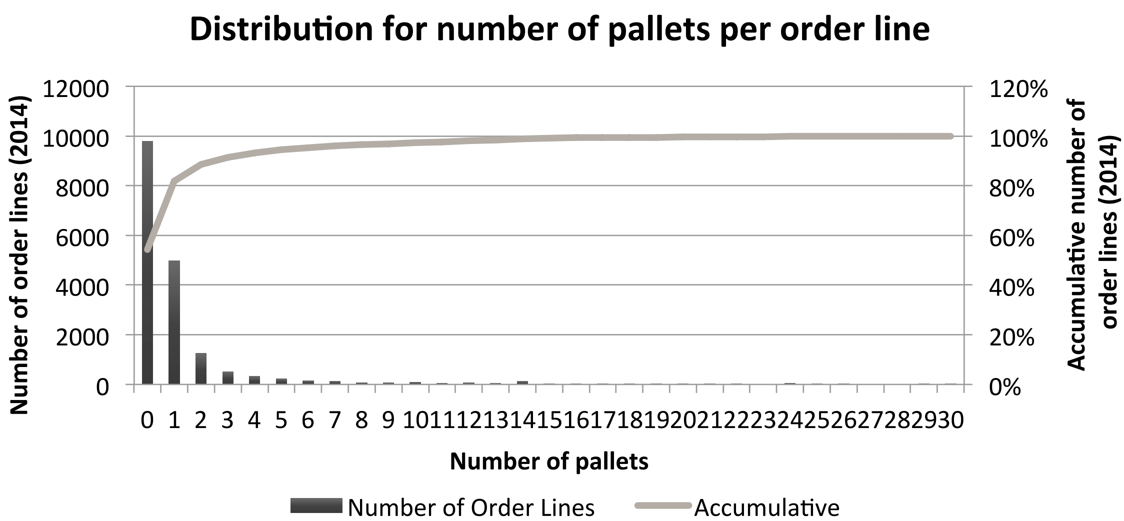


Figure 4.16. Distribution for number of pallet per order line based on sales 2014. "0" represents broken pallet picks.

Summary of Forecasting and expected demand – Demand patterns	
Findings	• Peak demand in beginning and end of the year • Peak storage around New Year's and summer • Greater demand during beginning and end of week • More pallets in storage during end of the week • Generally small orders seen to volume and number of SKUs • Varying number of pallets in storage per SKU
Output	• Warehouse storage must be able to store different number of pallets efficiently due to a considerably low peak-to-average ratio in number of pallets in storage • Focus on efficiency for smaller orders (up to 7 pallets)

4.4.2. Three scenarios to explore future demand

To find a warehouse design layout that will work in the future, three different scenarios have been developed with a business controller from Oatly; a *normal*, a *consolidation* and an *increase* scenario. The scenarios developed regard changes in the product portfolio size, change in number of distribution points as well as change in the sales volume. Trends in the marketplace towards more sustainable food production has led to that the plant-based dairy market in the world is expected to grow. An industry association believes that the market will grow with 66.7 % from 2013 to 2019. It will then include 10 122 million liters worldwide. (Sig Combitech, 2015) Oatly's volume turnover in 2015 is expected to be 27 million liters. The corporate strategy and planning currently in use at Oatly is developed to 2017. For this reason all scenarios use the same numbers used within the corporation for this time period. Except for when it comes to the distribution points. After 2018 the figures for the scenarios divert.

The product portfolio size, or the number of SKUs in the warehouse, affects the complexity of warehouse operations. The number of lanes needed for dedicated storage in the carton pick area is directly affected. The product portfolio size will also increase the information flow complexity as the likelihood an increased number of order lines per order is high. The changes in product portfolio are described for the three scenarios in table 4.9, 4.10 and 4.11. Major differences between the scenarios are the rate of introductions and the rate of discontinuation. In the normal scenario the introduction rate is kept stable with an increase of approximately 10 new products per year, see table 4.9. The discontinuations are fairly low with 3 products per year. In the increase scenario the introduction rate of new products is twice as high as in the normal case while the discontinuation rate is kept the same. This would yield a product portfolio of 163 products, as can be seen in table 4.10. In the consolidation scenario the introduction rate of new products is unchanged from the normal case while the amount of discontinuations increase. This yields a product portfolio of 102 products to be handled in the warehouse, see table 4.11.

Table 4.9. Product portfolio changes in the normal scenario.

Year	2014	2015	2016	2017	2018	2019	2020
Introductions	16	12	12	10	10	10	10
Discontinuations	3	3	3	3	3	3	3
Portfolio size	77	86	95	102	109	116	123

Table 4.10. Product portfolio changes in the increase scenario.

Year	2014	2015	2016	2017	2018	2019	2020
Introductions	16	12	12	20	20	20	20
Discontinuations	3	3	3	3	3	3	3
Portfolio size	77	86	95	112	129	146	163

Table 4.11. Product portfolio changes in the consolidation scenario.

Year	2014	2015	2016	2017	2018	2019	2020
Introductions	16	12	12	10	10	10	10
Discontinuations	3	3	3	3	10	10	10
Portfolio size	77	86	95	102	102	102	102

The number of pallets handled per year is expected to increase with the sales. An increase in the number of pallets handled per year affects not only the number of pallet positions needed and space requirements for activities in the warehouse. The increase will also put higher pressure on the work processes related to the material flow in the warehouse. The figures have been forecasted until 2017 and are considered reliable. For this reason there are no changes between the scenarios. From 2018 the three scenarios growth expectations divert. The normal case follows the current growth trend curve of the sales in the company. The forecasted growth in sales per year can be seen in table 4.12. All three scenarios have the same growth curve and are based on the normal case. The increase scenario assumes a 15 % higher outcome from normal scenario on a yearly basis. The consolidation scenario assumes a 15 % lower outcome than the normal scenario on a yearly basis. As a consequence, both the increase and consolidation scenario follow the normal growth thus not generating either a bad-follow-bad or good-follow-good scenario. These numbers are used to calculate the growth of all activities in the warehouse related to the growth of sales. The forecasted amount of pallets handled per year is shown in figure 4.17.

Table 4.12. Growth figures used in the normal scenario

Year	2015	2016	2017	2018	2019	2020
Growth	Baseline	31%	26%	29%	21%	22%

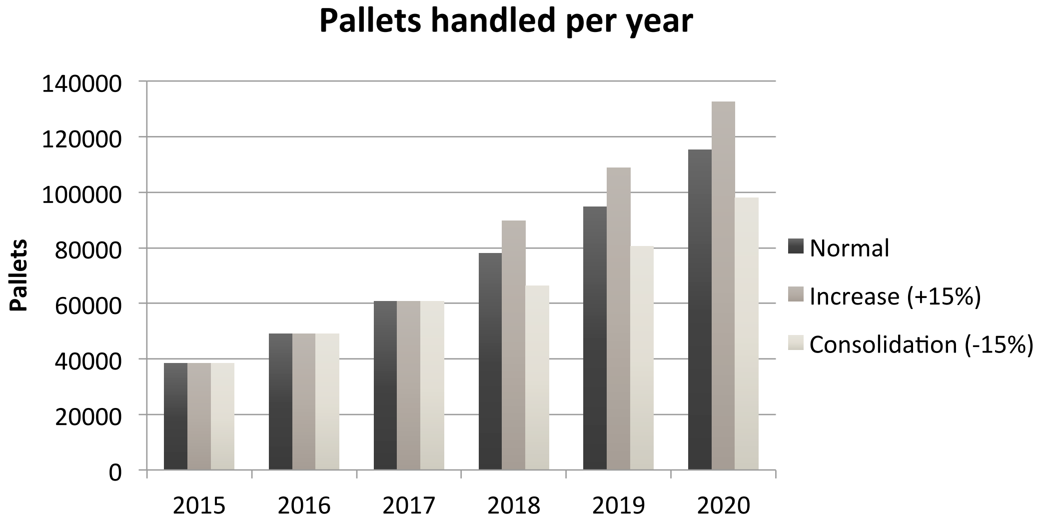


Figure 4.17. Forecast over amount of pallets handled until 2020 in the different scenarios.

The number of distribution points connected to the warehouse affects the number of orders expected per week. Oatly defines a distribution point as a customer or the location that receives an order. Food retail chains often have several distribution warehouses. These are considered one distribution point each. Oatly believes that the amount of orders per week per customer will not change while the orders are likely to include more pallets. The distribution points increase for the normal and increase scenarios while it remains the same as today in the consolidation case. Table 4.13. shows the expected increase in number of distribution points until 2020 for the scenarios.

Table 4.13. Expected changes in number of distribution points up to 2020

Scenario	Change	Distribution points
Normal	+10	114
Consolidation	0	104
Increase	+20	124

During a week approximately 83 % of the customers send in customer orders. This means that the average number of orders per week is 86 orders in today's operations. Both the weekly seasonality described as well as the proportion of customers sending in customer orders per week are considered to remain the same. The number of orders for the coming five years considering the growth scenarios is found in table 4.14.

Table 4.14. Orders per week until 2020.

Orders per week	2015	2016	2017	2018	2019	2020
Normal	86	88	90	91	93	95
Consolidation	86	86	86	86	86	86
Increase	86	90	93	96	100	103

The number of orders per week is expected to affect the shipping docks as well as the square area for inbound and outbound activities. The number of pallet per order is expected to increase. Using the pallets handled per year in the three scenarios and divided with the number of orders can yield an average number of pallets per orders that can be used in the following steps to calculate space requirements for the I/O square and shipping docks. The average number of pallets per order for the five-year period is visualized in table 4.15. The distribution of the number of pallets per order is likely to look similar to figure 4.17.

Table 4.15. The average number of pallets per order for the three scenarios normal, increase and consolidation

Average number of pallets per order	2015	2016	2017	2018	2019	2020
Normal	8.6	10.7	13.0	16.4	19.6	23.4
Consolidation	8.6	10.9	13.5	14.8	17.9	21.8
Increase	8.6	10.5	12.6	17.9	21.0	24.8

The number of pallet positions needed in the Oatly warehouse is calculated for the three future scenarios. In all scenarios the proportion between chilled and ambient pallet positions (50-50) are assumed to remain unchanged. The number of pallet positions needed has been calculated by using two different storage utilization rates, 67 % and 86 %, measured as occupied pallet position through the total number of pallet positions. The target utilization rate 67 % is the average storage utilization in the warehouse today and 86 % is according to Frazelle (2002) the maximum utilization rate for a warehouse to avoid disruptions due to congestion. The processes in the warehouse are not considered to be able to achieve a 86 % storage utilization on average without a fully integrated Warehouse Management System, adapted material flows and optimal lane depths. However, during peaks in demand the warehouse can with the help of double handling and additional resources come up to levels over 80 % according to the warehouse manager. Further, the pallet positions have been divided into *Nordic*, *export* and *private label* to enable analysis of the three material flows. The export and private label goods are subject for discussions about outsourcing, using 3PL storage, which would decrease the demand for pallet positions in the warehouse. Both the export and private label products are ambient, which is considered easier to outsource as it lowers the requirements on the distribution chain.

For the normal scenario the amount of pallet positions needed for an assumed utilization of 67 % and 86 % are shown in Figure 4.18. and 4.19 respectively. The peak number of pallets in a year is close to the pallet positions needed in 2020 if 86 % utilization rate is accomplished. The peak to average ratio calculated with is 1.24 and decreasing to 1.14 in a steadily pace during the five year period. The peak number of pallets during a year will increase steadily and surpasses the current number of pallet positions in 2018. Looking at the average number of pallet positions needed it is visualized that the current warehouse solution will need to be increased either 2017 or 2018 depending on the average utilization rate achieved.

Oatly's facility in Landskrona is subject to many projects to cope with the expected growth. For this reason rebuilding the warehouse can be postponed and outsourcing of private label or export flow is considered. When outsourcing goods the demand on required number of pallet positions decrease to a level that is manageable within this time frame. Figure 4.20. and 4.21 show a possible outsourcing strategy for the 67 % and 86 % utilization situations respectively. In both situations the current amount of pallet positions will suffice until 2020. The difference between the situations is due to that more pallet positions per division is needed for the 67 % utilization rate. For this reason the larger division export is outsourced earlier in the 67 % situation than in the 86 % situation. After 2020 the Nordic demand alone will exceed the current capacity in both cases.

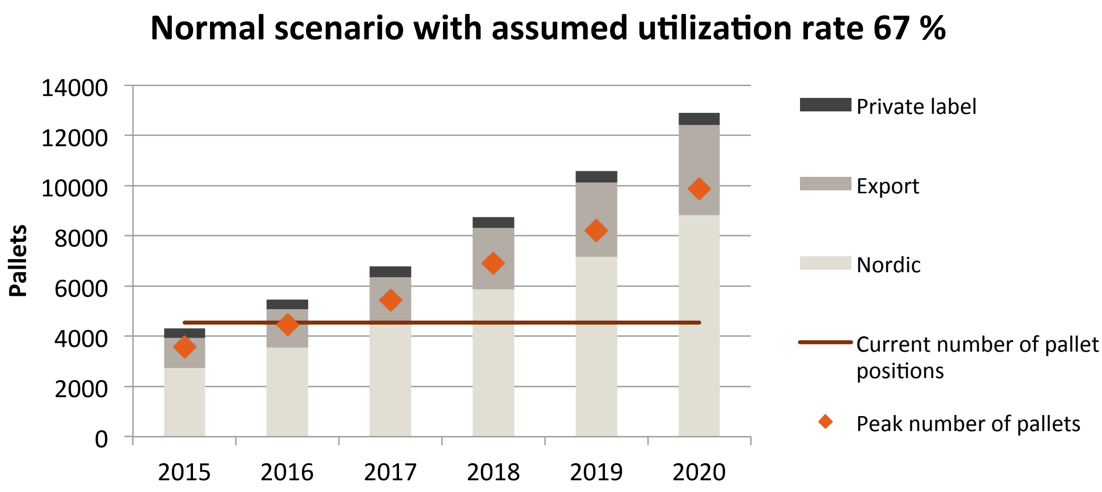


Figure 4.18. Pallet positions needed in the Oatly warehouse in the normal scenario with an assumed utilization of 67 %.

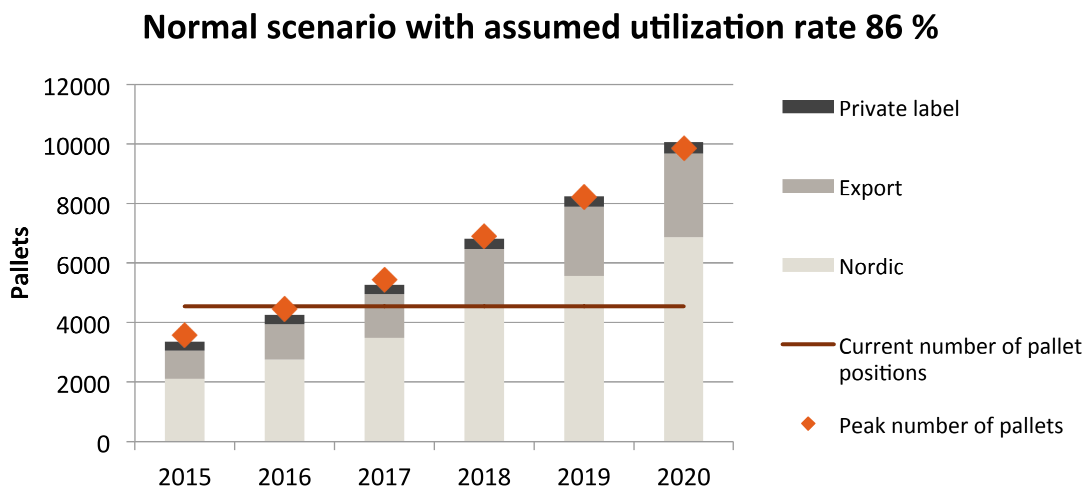


Figure 4.19. Pallet positions needed in the Oatly warehouse in the normal scenario with an assumed utilization of 86 %.

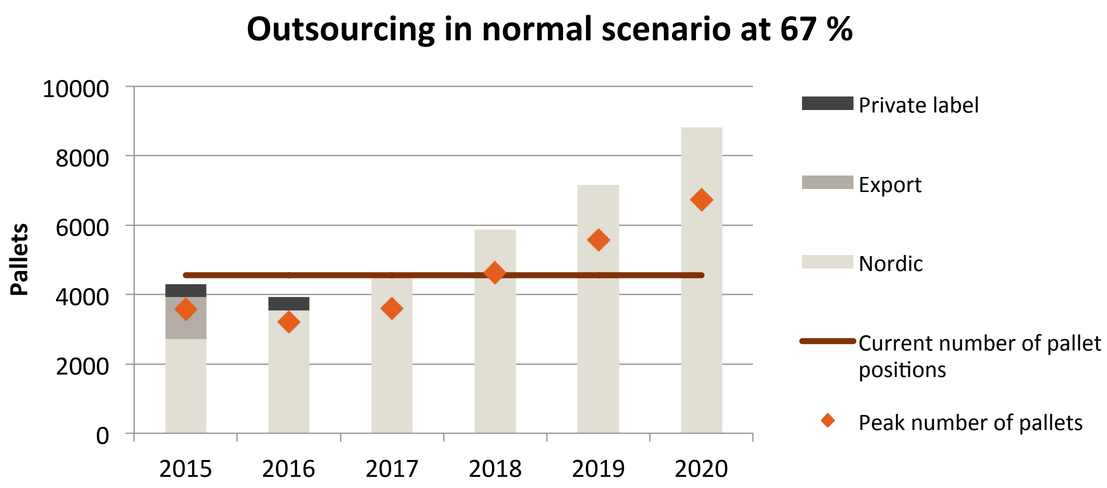


Figure 4.20. Pallet position demand with outsourcing of export and private label goods in the normal scenario at 67 % utilization.

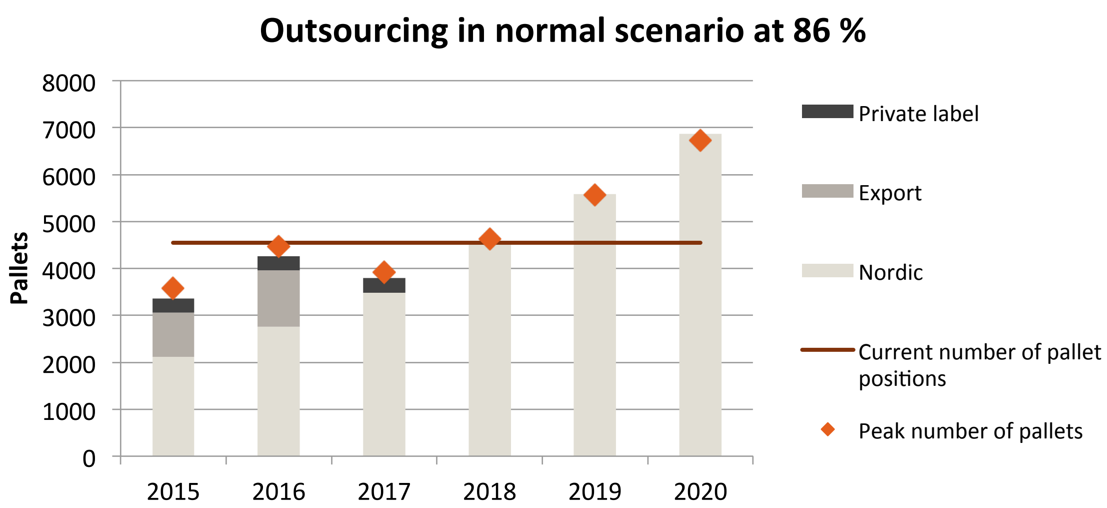


Figure 4.21. Pallet position demand with outsourcing of export and private label goods in the normal scenario at 86 % utilization

The corresponding figures for the remaining two scenarios, increase and consolidation can be found in appendix A. Due to the steeper growth in the increase scenario the current capacity will be exceeded faster than in the normal case. In both cases this will happen around 2018. The pallet positions needed in 2020 with 67 % utilization is approximately 18 000 which is more than three times the current capacity. Outsourcing of the export and private label goods in the increase scenario will be able to handle the demand until approximately 2018. Then the Nordic demand will exceed the capacity of the current warehouse. For the 67 % the private label goods will be outsourced 2017 and the export 2016. For the 86 % situation the private label will be outsourced for storage in 2018 and the export in 2017.

In the consolidation scenario the exceeding amount of pallet positions are lower due to the slower increase in expected growth. The result of the slow growth is primarily shown for the Nordic goods which merely exceeds the current warehouse capacity in 2020 in the 86 % scenario. However, in the 67 % scenario the Nordics breach the maximum capacity in 2018. The outsourcing of the private label and export will occur in 2017 and 2016 respectively. In the 86 % scenario the outsourcing takes place 2018 and 2017 respectively.

The suggested outsourcing scenario which will be used further on in this study is presented in figure 4.22. The figures used are for the normal case with 67 % space utilization. The suggested outsourcing scenario differs from the one presented for the 67 % situation as all the material flows are brought back in-house in 2020. The warehouse layout which will be developed will consider the full material flow in 2020. The peak number of pallets in the warehouse for the normal scenario and the material flows is presented for each year. For the total material flow in 2020 the peak number of pallets in store is presented for all three scenarios to show the interval of number of pallet positions needed in the warehouse to consider.

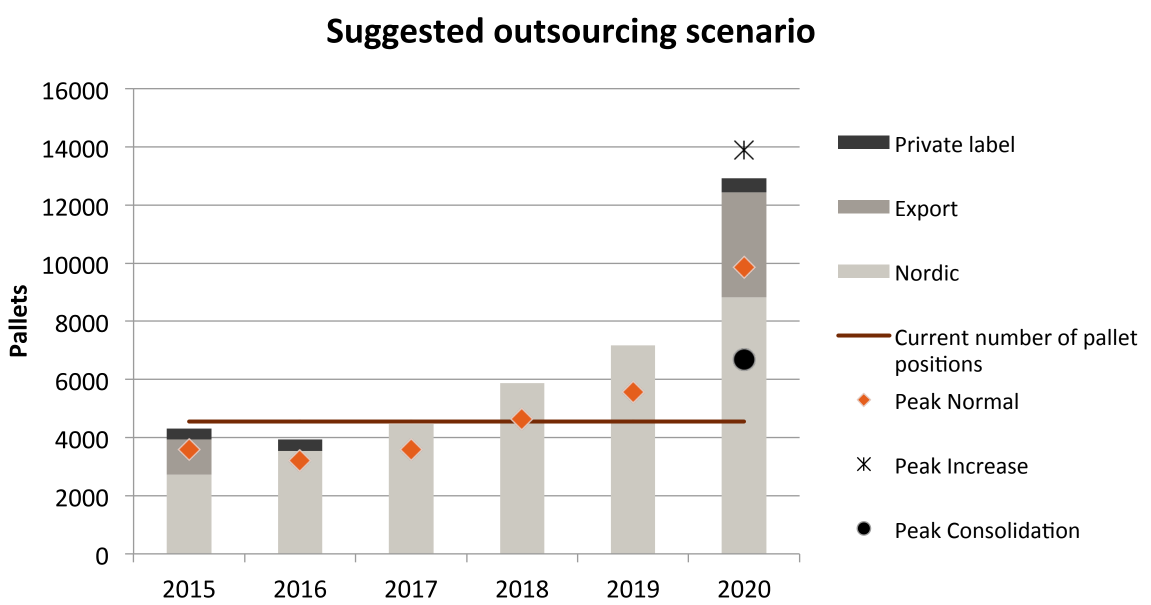


Figure 4.22. Suggested outsourcing scenario in the normal case.

Summary of Forecasting and expected demand – Three scenarios for future demand	
Findings	• Storage is not sufficient to 2020 regardless of outsourcing • Outsourcing of export and private label goods can yield a sufficient solution until 2017 than the Nordic material flow will be too large for the Oatly warehouse
Output	• Warehouse should be flexible towards all three scenarios • Three scenarios depending on the expected growth in three dimensions • Outsourcing of storage is a must to keep operations running

4.5. Analyze Warehouse Equipment Setup

When analyzing the warehouse equipment setup it is important to consider product characteristics, volumes and requirements. Further, the equipment setup also needs to be suitable for the dispatching policies of the products as well as regard the space efficiency. This can be provided with different amounts of automation in the processes. In the Oatly warehouse different types of equipment setups are considered for the different products. Parts of the products require a flexible type of system that can efficiently hold low volume products and is flexible to an increased number of articles in the product mix. Large volume products are however more suitable for the current system with deep lane maxi-packers as the maxi-packers are space efficient and ensures a FIFO dispatching policy. The maxi-packers are semi-automated and moves pallets within the deep lanes automatically which yields a lower risk for damage on the pallets. In this section different warehouse equipment setup alternatives are assessed based on space efficiency, cost and honeycombing.

The products mainly stored in the Oatly warehouse are perishable, both the raw material and the finished products. For this reason the warehouse has a strict FIFO dispatching policy for the finished goods out to customers. The raw material can sometimes have expiring dates that do not match the order of the delivery dates. For this reason the raw material have a FEFO dispatching policy for the raw material. Apart from the strict dispatch policy, each pallet with finished products can become subject to laboratory tests. The laboratory tests are conducted on a specific individual pallet which leads to that the pallets need to be accessible if double handling of pallets is to be avoided. The pallets stored at the Oatly warehouse are considerably heavy, on average 720 kg per pallet which causes restrictions of the equipment setup. The current equipment setup in the Oatly warehouse consists of both deep lane maxi-packers and single-deep racks, with approximately 86 % of the pallet positions in deep-lane storage. The smallest units stored are broken pallets why the warehouse equipment setups analyzed in this part are only pallet storage. The total number of pallets ordered per article in 2014 is visualized in figure 4.23. It is evident that a few articles stand for the majority of the volume, even exceeding the Pareto principle of 80-20. These articles are suitable for a space efficient racks setup. Low volume products are however more suitable for a more flexible rack setup since they often recently have been introduced to the market with many flavors and small flows.

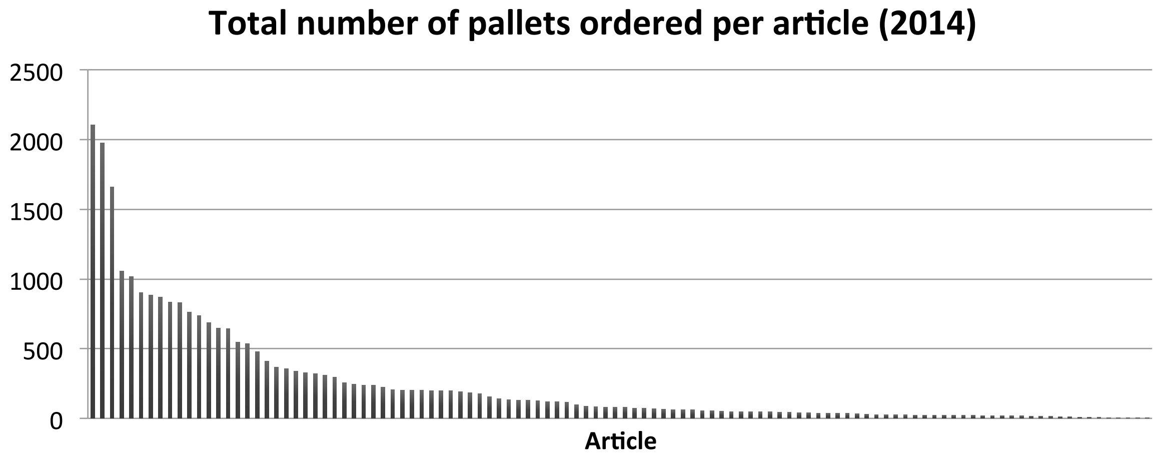


Figure 4.23. Total number of pallets ordered per article based on sales from 2014.

In figure 4.24. the articles popularity in terms of number of times requested and volume in terms of number of pallets shipped during 2014 is visualized. The articles that are requested most frequently are not the same as the products with the largest volume flow. The majority of the articles handled are low volume and low frequency.

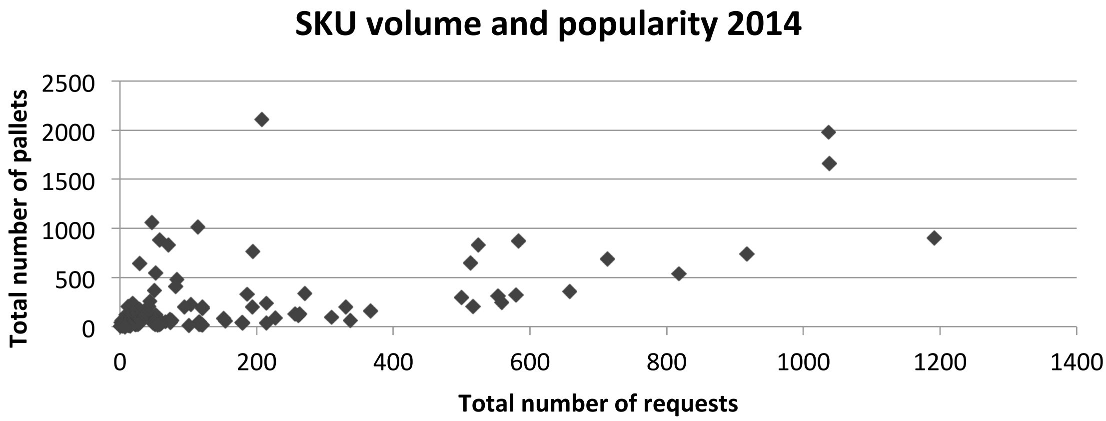


Figure 4.24. Volume and popularity for every article based on sales figures from 2014

The exact proportion of pallet positions for each rack system is hard to forecast with the current data available. Therefore the equipment setup size has been analyzed qualitatively with the help of the warehouse manager and the order data from 2014. An ABC classification of the number of pallets in storage is shown in table 4.16. The ABC classification is used to get an approximation of the maximum proportion of pallet positions needed in the deep lane storage. It is considered that the proportion of deep lane storage should not be over 65 % to keep the warehouse flexible towards the new material flows by reducing the possibility of honey combing waste. The current warehouse solution has 86 % of the pallet positions allocated to deep lane equipment setups.

Table 4.16. ABC storage classification based on number of pallets in storage.

Storage Classification	Percentage of pallets in storage	Percentage of articles
A (>50)	65%	20%
B (12<B<50)	30%	43%
C (<12)	5%	37%

In many warehouse equipment setups on of the main decisions is whether or not the handling is efficient and sufficient enough for the flow of goods through the warehouse. In the Oatly warehouse the current automation are the automated pallet movers placing the pallets in the deep storage racks. Apart from the movers, no automation has been needed for the activities. Even with the future demand a simple automation system, like the one in use today, might be suitable for efficiency reasons. Seen to the Naish and Baker automation framework the Oatly warehouse will not exceed 200 pallets per hour within the given time frame and the number of SKUs can be seen as small. As a result either a mechanical assistance or simple automation solution is suitable. Also seen to the Naish and Baker decision framework most automation can be discarded due to infeasibility primarily regarding cost and throughput needed for higher level of automation.

For warehouse equipment setups it is important to consider the lane depth. The optimal lane depth can be calculated in several ways as previously stated in theory. Considering the decision criteria identified in step 1 the solution should have high space utilization, regard for volume and product flexibility and minimize double handling. It was found in step 2 that the double handling is incurred when movements from the deep lanes are needed free up the whole lane thus maintaining some flexibility of the rack setup. The optimal lane depth for the Oatly warehouse has been calculated with Bartholdi and Hackman (2014) Theorem 6.1. presented in the frame of reference. The order quantity for the products is divided into Landskrona production and production from subcontractors. The average number of pallets per batch in the Landskrona production is 14 pallets and 30 pallets for subcontractors which constitutes a truckload. Aisle width is considered 3m as this is the standard measurement in the warehouse today. For the deep lane rack systems two aisles are needed to access the pallets, why 6 m are used as aisle width as well. For both order quantities the optimal lane depth is considerably smaller than the current maxi-packers, 5 and 7 pallet positions deep respectively for systems with one aisle. The optimal lane depth for systems with a need for two aisles for accessibility is slightly higher with 6 or 9 pallet positions deep lanes. The optimal lane depth is shown in table 4.17. For comparison the order quantity which yields the optimal lane depth of 35 and 21 pallet positions are 817 and 294 pallets and 408 and 147 pallets for rack systems with two aisles. According to theory, the accessibility and flexibility decreases with the increase of lane depth (Bartholdi & Hackman, 2014; Frazelle, 2002). This is why the lane depth considered for the Oatly warehouse is lower than in the current solution.

Table 4.17. Optimal lane depth regarding space utilization according to Theorem 6.1. (Bartholdi & Hackman, 2014). Aisle width is considered to be doubled for deep lane racks which require two aisles for accessibility.

Production	q (order quantity)	a (aisle width)	Optimal lane depth
Landskrona	14	3	5
Subcontractors	30	3	7
Landskrona	14	6	6
Subcontractors	30	6	9

Apart from lane depth it is also important to consider the combined cost of racks and equipment. Deeper lanes often require special equipment such as long reach trucks to be able to move the pallets out of the racks. It is also possible to use rack systems that move the pallet forward automatically such as tilted racks or semi-automated rack systems, such as the maxi-packers currently in use at the warehouse. Evaluations of seven different kinds of equipment setups can be seen in table 4.18. The different equipment setups are compared in three measures found in the literature review; cost per pallet position, space efficiency, yearly honeycombing. Cost per pallet position is calculated as the cost of the rack section divided by the number of pallet positions in it and necessary equipment costs are mentioned for one item per equipment to be able to compare the systems in a simple way. The space efficiency of the system is measured in m^2 floor space which is preoccupied per pallet position. It is calculated as the aisle space necessary to access the pallet plus the space of the actual rack divided by the number of levels in the system. The yearly honeycombing waste calculated according to Bartholdi and Hackman's (2014) formula for yearly honeycombing waste. It is calculated for one of Oatly's own products with a high volume. Honeycombing is more likely to occur the deeper the lane is while space efficiency is reversed depending on the number of levels in the rack system. Benefits and drawbacks with the different equipment setups are described hereafter.

Table 4.18. Comparison of different equipment setups for the Oatly Warehouse.

Equipment setups (rack + equipment)	Lane depth	Cost (per pp. + equipment)	Space efficiency	Total cost per pp for new builds (racks and building)	Yearly honey-combing waste
Single-deep	1	SEK 250	0.48	SEK 6 217	0.000
Truck UMS-160		SEK 300 000			
Single-deep	1	SEK 250	0.40	SEK 5 188	0.000
Truck URS - 1250		SEK 600 000			
Double-deep	2	SEK 250	0.36	SEK 4 674	0.033
UMS TF - 200		SEK 355 000			
Multi-deep maxi-packer	35	SEK 0	0.24	SEK 6 463	1.128
Truck UMS-160		SEK 300 000			
Multi-deep maxi-packer	21	SEK 0	0.30	SEK 7 204	0.664
Truck UMS-160		SEK 300 000			
Roll racks	6	SEK 3 500	0.30	SEK 7 204	0.166
Truck UMS-160		SEK 300 000			
Changing maxi-packer	17, 12	SEK 141	0.27	SEK 6 974	0.498
Truck UMS-160		SEK 300 000			

The single-deep racks are currently used for both finished goods and raw material. Single-deep racks provide maximum accessibility of all pallets in storage which means that it can handle all types of dispatching policies. However, to maintain a strict dispatching policy the warehouse requires a sophisticated administration process, such as a warehouse management system, that can keep track of pallets on an individual level therefore being able to allocate the right pallet to each incoming order. In a single-deep pallet rack no pallets are blocked which means that there is no risk of honeycombing waste. As the most frequently ordered number of pallets per article in the Oatly warehouse is one or less than one the single-deep racks are suitable to minimize honeycombing waste by making sure that the slot is emptied with each order. As Oatly's current corporate strategy is to differentiate by introducing new products it is bound that many new articles have small product flows. Single-deep racks are flexible towards different sizes of product flows. Single-deep racks do not incur any honeycombing waste at all as no pallet positions can be blocked. The biggest flaw of single-deep racks is their space inefficiency since the need for aisle exposure. Therefore, half of an aisle must be added to every single-deep rack. The Oatly warehouse has capacity to have single-deep racks in 6 levels which increases the floor space utilization to some extent. The forklift trucks needed for the rack setup are reach trucks being able to lift the pallet up to the sixth level. If a narrow aisle truck is used the width of the aisles can be decreased from 3 m to 2 m thus increasing space efficiency. However, a narrower aisle can lead to congestion and requires more precision from truck drivers. This can increase the safety risk for the employees as well as the damage risk of the pallets. The extra precision required decreases the speed of the picking and put-away activities which can lead to increased operational costs.

A similar solution to single-deep racks are double-deep racks which have almost the same benefits as the single-deep racks. Double-deep racks are more space efficient than single-deep racks as two pallet positions shares the same aisle space. The double-deep racks are however subject to honeycombing waste as slots can be blocked for storage to avoid double handling. Double-deep racks are less accessible than the single-deep racks as one pallet is blocked per slot. Neither the single-deep racks nor the double-deep racks require automation or mechanical solutions. This means that these rack systems are relatively cheap. Comparing the total cost per pallet position for new builds the double-deep racks are the most cost efficient solutions. Double-deep racks require forklift trucks which can extend their forks. These types of trucks are often a more expensive than ordinary reach trucks.

The deep lane equipment setups considered are the maxi-packer, currently in use at the Oatly warehouse, and racks with rollers that use elevation to move pallets, so called roll racks. The reason why only these types of deep storage are considered is due to the ensuring and facilitation of a FIFO dispatch policy. The deep lane equipment setups are space efficient per pallet position as only two aisles are needed to access a large number of pallets. The deep lanes also ensures a FIFO policy among the pallets in the lane without the need for extra administration or handling. However, as only one pallet is accessible in each slot the accessibility of these systems can be considered as low. Significant double handling can be needed if a pallet in the middle of the lane is required for laboratory tests. The deep lanes also incur significant amounts of honeycombing waste due to many blocked pallet positions which becomes more and more significant with the lane depth. In both of these equipment setups the trucks used are standard forklift trucks for pallet handling. The difference between the roll racks and the maxi-packers are the system for moving the pallets in the lane. The maxi-packers are semi-automated and have a robot to move the pallets into the racks. The maxi-packer equipment setup is shown in figure 4.25. The maxi-packer in the Oatly warehouse is five levels high in contrast to the figure which shows four. The 35-deep maxi-packer considered in the comparison sheet has the best floor space efficiency of the considered systems. However, it is subject to honeycombing considerably higher than the system which has the second highest honeycombing waste.

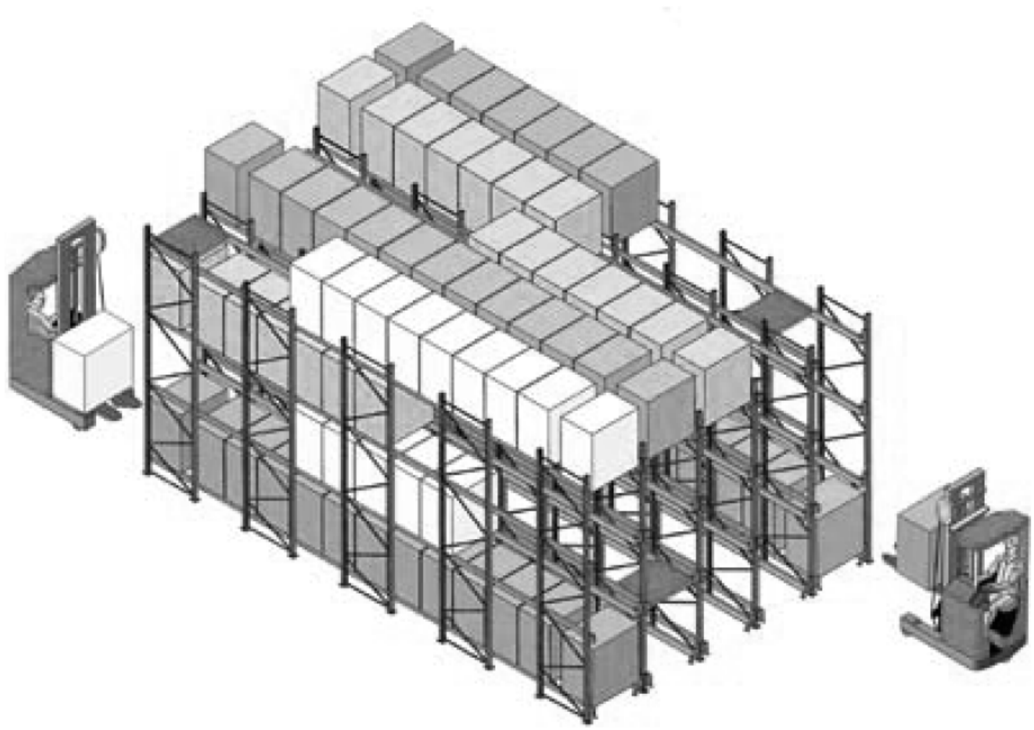


Figure 4.25. Maxi-packer system (Hyllbörsen.se, 2006).

The roll racks considered use rollers to mechanically move the pallets through the lane. To ensure a movement the racks needs to be elevated with 4 %, see figure 4.26. The pallet loads feasible in this solution is dependent on the weight of the pallet loads. As the optimal lane depth calculated is six for double aisle rack setups this is the depth investigated. It is also considered that the number of levels in a roll rack system will be five in the Oatly warehouse.

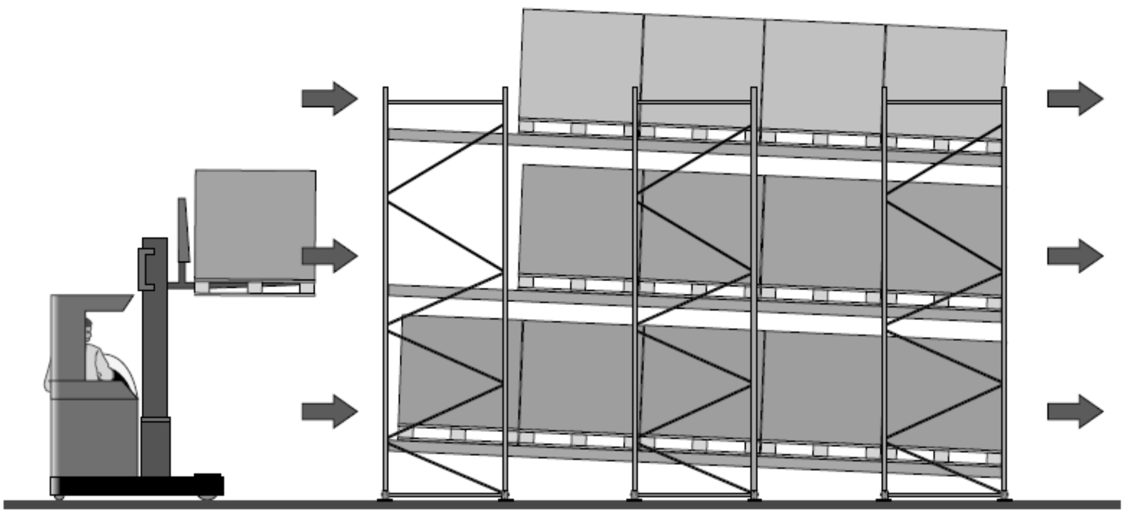


Figure 4.26. Roll-racks (Hyllbörsen.se)

Summary of Warehouse Equipment Setup	
Findings	• Need for a flexible equipment setup with a bigger spread of lane depth • 65 % of the volume come form 20 % of the products • Rack lanes should be shorter than the current setup provides • Equipment must facilitate FIFO-policy to the largest extent possible
Output	• Shorter lanes result in less honeycombing • Shorter lanes result in better flexibility and storage efficiency • Long lanes are more space efficient for high volume goods • Need for different types of storage systems with different lane depth

4.6. Plan Space Requirements

Planning space requirements for the Oatly warehouse is based on the future demand scenarios presented in step 4. The potential outsourcing of material flows will affect the space required in the warehouse. From here on the pallet flows considered will follow the outsourcing scenario found in step 4. The private label and export is outsourced gradually until 2020 when all material flow moves back in-house. The roof of the demand for the warehouse in Landskrona is considered to be the maximum capacity expected for the Landskrona production site on 80 million liters which yields approximately 115 000 pallets handled per year.

In this step the space requirements for all activities performed in the warehouse is planned in rough estimates for 2020, when all material flow is taken back in-house, to be able to start the warehouse layout design step. Apart from put-away, storage and picking, warehouses are today including more and more activities. In the Oatly warehouse the ancillary activities that have been identified are repacking from ordinary pallets to expo pallets as well as laboratory tests. These activities take up space in the warehouse. When the automated line from production is in place, space must be allocated to the pallet-mounting machine currently placed in the production line as well space for the conveyor lines. As the expected change in demand is calculated to change the number of pallets per order while the number of orders remains fairly stable the demand for square space in connection to the docks increases rapidly. The number of docks required according to calculations is not needed to be increased. The space requirements planned for 2020 is presented in table 4.19. and will be further described throughout this chapter.

Table 4.19. Overview of space requirements in the warehouse 2020 for the three scenarios if all material flow is kept at the Oatly warehouse

Space need	**Increase scenario 2020**	**Normal scenario 2020**	**Consolidation scenario 2020**	**Current warehouse 2015**
Docks	4	4	4	4
Square (m^2)	687	597	508	171
Flammable products (pp)	32	32	32	32
Equipment I/O and loading	43	43	43	43
Technology	13	13	13	13
Raw material (on square)	25.92	25.92	25.92	25.92
Wrapstation (m^2)	9.2	9.2	9.2	9.2
Packstation expo pallets (m^2)	8.2	8.2	8.2	8.2
Pack station parcels (m^2)	6.9	6.9	6.9	6.9
Pallet positions accessible	3	3	3	0
Aisles	-	-	-	-
Pallet positions needed in peak	8794	6735	4238	-
Carton pick pallet positions	163	123	102	36
Future needs	**Increase scenario 2020**	**Normal scenario 2020**	**Consolidation scenario 2020**	**Current warehouse 2015**
Pallet changer (m^2)	9.2	9.2	9.2	0
Product development activities	80+40	80+40	80+40	0
Marketing activities	(100)	(100)	(100)	(100)

The change in the amount of orders is assumed to change with the increase of distribution points according to the three scenarios, as can be seen in table 4.13. Therefore, the time occupied per dock and the I/O squares will increase. In table 4.20. the expected time occupation of docks in 2020 for the three scenarios are presented per weekday. The orders per week have been distributed to the different weekdays with the percentage of orders per weekday from the order data from 2014. The duration of a loading of a lorry has been observed at the warehouse in Landskrona with 22 data points. The average time a lorry occupies a dock after arrival is 19.6 minutes which has been used to calculate the time per weekday when the docks are occupied.

Table 4.20. Time per weekday (hours) when a lorry occupies a dock to load outgoing orders in 2020.

	Normal	Increase	Consolidation
Monday	7.5	8.1	6.8
Tuesday	6.3	6.8	5.7
Wednesday	4.7	5.1	4.3
Thursday	5.8	6.3	5.3
Friday	6.6	7.2	6.0

The Oatly warehouse has four docks which are used for both in- and outbound material flow. As seen in table 4.20. the increase scenario has the longest expected time per day of occupied time in a dock is 8.1 hours on Mondays 2020. Dividing this time on the four docks available renders approximately 2 hours per dock occupied per day. This means that there is no need for an increased number of docks regarding the shipping activity. However, the lorries arrival times is hard to forecast as external transport companies are hired. This means that they can arrive at any time of the day which could lead to queues during high pressure hours. As the warehouse today has two temperature zones, one can consider that there are two docks available. In the data analyzed it has not been possible to separate the material flow to the two departments which also can affect the solution. The docks are currently used for incoming material as well, both from the production in Landskrona and from subcontractors. The material inflow from the production in Landskrona is expected to change into an automated line within the foreseeable future thus not adding pressure to the docks. The subcontractor shipments are planned with the weekly number of order profile in mind which means that they receive orders on Wednesdays, when the weekly minima occurs. For this reason the docks needed for the receiving activity is not considered to change the number of docks needed in the final solution.

Observations and interviews at the Oatly warehouse has shown that the bottleneck in the receiving and shipping lie in the I/O square which is often full of outgoing orders. Storage of incoming material and remaining outgoing orders are as a consequence temporarily put in aisles. Aisle storage results in accessibility problems, congestion and blocking of emergency exists. The average number of pallets ordered per weekday in 2020 for the three scenarios is visualized in table 4.21.

Table 4.21. Number of pallets ordered per weekday in 2020

	Normal	Increase	Consolidation
Monday	622	716	529
Tuesday	341	392	290
Wednesday	290	333	246
Thursday	441	507	375
Friday	524	603	445

The current I/O square has room for 171 pallets in marked spaces, which is too small for the current operations and will not serve its purpose well in any scenario in 2020. A larger I/O square would temporarily solve this storage issue. However, in all cases it would incur that the I/O square need to be many times larger than it is today. In all three scenarios the future square size needed to handle the weekly average peak is above 500 pallets. The square meters needed to hold the average number of pallets ordered for the different scenarios can be viewed in table 4.22., where all pallets are calculated as EUR-pallets with a base area of 0.96 m^2. It can be seen that the size of the square needs to be above 500 m^2 which stands for approximately 17.5% of today's total warehouse area.

Table 4.22. Area (m^2) needed in 2020 for outgoing pallets

	Normal	Increase	Consolidation
Monday	597	687	508
Tuesday	327	376	278
Wednesday	278	320	237
Thursday	424	487	360
Friday	503	578	428

As all pallets ordered is picked and put on the I/O square the day before the I/O square would need to be increased beyond the average numbers stated in table 4.22. The peak-to-average ratio on the pallets ordered in one weekday is high, 2.51, as stated in step 4. This means that if the current operations setup is maintained the need for space could be up to 1227 m^2 in the docking area. With changed processes this area would be able to be smaller. Scheduling the shipping transports could enable a higher turnover on the I/O square which in turn can lead to a decrease in space requirements. However, this is not issue free. Oatly's current domestic transport providers does not offer scheduled pick-ups as they route their shipments. The export picks-ups can be somewhat scheduled. While material flow is outsourced the square size requirements change with the material flow in the warehouse. It has not been possible to analyze how the change in order flows will affect the number of pallet ordered per weekday. But the products outsourced in private label and export is high. Almost all full truckload orders are for these material flows. This would mean that the average number of pallet per order in the Oatly warehouse would decrease and with it average number of pallets ordered per weekday. Table 4.23. shows the square size requirements in square meters for an average number of pallets ordered on Mondays. Even though material flows are outsourced and that the orders that remain are likely to be smaller than the current orders the size of the squares need to increase as the space required for 2015 is larger than the size of the squares today.

Table 4.23. Square size (m^2) required for the average number of pallets ordered on Mondays in the normal scenario

	2015	2016	2017	2018	2019	2020
Square size (m^2)	199	253	294	271	331	597

In the current warehouse layout there is a room for equipment and one room for flammable raw material. Both of these rooms are specially prepared with temperature settings and fire doors. Interviews with warehouse manager and supply chain coordinator expects the space requirements for these rooms to remain the same. The truck-room today holds the full number of battery driven forklift trucks in the warehouse. However, as the demand for additional equipment in the warehouse will increase the charging process in the warehouse would need to change. The new set-up planned would mean that each truck has two batteries. So that one is in the charging room and that the batteries are changed on the truck out in the warehouse when needed. Space requirements wise it is enough to have room for the batteries and a battery changer in the truck room instead of all the trucks which would alleviate space.

The raw material storage space requirements in the ambient department will be smaller than today as soon as the production facility is extended. However, raw material in need of chilled storage, besides the flammable raw materials, will remain in the warehouse as it is expensive to build a chilled storage in addition to the production.

The product mix is forecasted to expand and all products sold on the Swedish market are subject to less than pallet picks. For this reason the number of pallet positions available in an ergonomic level needs to be increased with the product portfolio size until 2020. For this reason single-deep pallet racks are needed which can have the lowest level for broken pallets for tray picks.

The repacking to expo-pallets will not be performed in the warehouse while the private label material flow is outsourced. The repacking is currently done in the end of the aisle for raw material. This is mainly due to the slow movements of the raw material which means that the likeliness that the activity would disturb the daily operations is lower. However, since the raw material is subject to be moved to the production site, the turnover in this aisle is likely to increase. As a result, the current position of the repacking station might become unsuitable. The demand is forecasted to increase for expo-pallets for the product that is currently packed on them. Additionally more products might be starting to be packed in expo pallets as sales increase and consequently the flow in food retail chains. The repacking is not conducted during the entire shift in today's operations which means that it is not a constraining factor. The space that is used in the aisle for repacking is 6.4 m^2. This space requirement is likely to remain the same but will be considered to get a designated area close to the wrapping station. The wrapping station requires 8.4 m^2.

The mapping of activities in the warehouse identified laboratory identification of pallets as a necessary but non-value adding activity that can disrupt the storage activity in the warehouse. The space requirement from this activity is for the pallets under investigation. These extracted pallets are currently often placed in an aisle or on the I/O square, if there is room. Pallets are not tested often. The amount of pallets being tested is approximately 2-3 per month. However, as the pallets chosen needs to be accessible after identification their placement can be highly congesting. To avoid this, approximately 3 pallet positions, or 3 m^2, need to be dedicated for the tested pallets.

The future activities considered for the warehouse are pallet mounting, pallet changer, product development activities and marketing department activities. The pallet mounting activity is dependent on the decision of introducing an automated line from the production facility in Landskrona to the warehouse with trays or whole pallets. In both cases space requirements for a pallet line is needed. If trays are chosen the pallet mounting is moved to the warehouse which will take up 9.2 m^2. If other pallets than standard EUR-pallets are demanded a pallet change can be installed to facilitate less time-consuming pallet changes. The pallet changes will occupy space assumed to be 10 m^2. The product development department has expressed a demand for pallets in both the chilled and ambient parts of the warehouse. 80 pallet positions in the chilled and 40 pallets in the ambient part are demanded. The marketing department has not expressed any special demand regarding pallet positions. The demand has been assumed to be 100 pallet positions the ambient part of the warehouse.

Summary of Space Requirements	
Findings	• Ancillary activities will occupy space in the warehouse • Docks are not highly utilized
Output	• No increase in number of docks • Ancillary activities must be considered in the layout • Larger I/O square area is required

4.7. Prepare Possible Warehouse Layouts

When designing the possible warehouse layouts, placement of receiving and shipping docks, aisle configuration and equipment setups for storage are considered. The objective of a warehouse layout design is primarily to use the space efficiently and to allow for the most efficient material handling. The prepared layouts all have their starting position in the current layout solution at Oatly. For several reasons, changes will be made to the layout. The primary reason to change the layout design is the rapidly increasing demand. One of the reasons why the warehouse will become insufficient in the near future is due to changes in the product portfolio. Since the current warehouse was built the product portfolio has more than doubled. The break-up orders, or tray picks, have also increased which is why additional focus is set on the tray pick area. The changes in demand are largely due to the change in corporate strategy. Lane depth, layout and number of available tray picking positions are consequently dimensioned for the former type of operation. In this section the warehouse layout solutions will be investigated.

All prepared layouts from the study are not presented, merely the ones most promising. The layouts suggested in this section can be divided into three parts; inside the current facility, building an additional 50 % to the long side and new expansions. Many of the layout suggestions are modular which means that they can be combined to find the best solution during the time frame needed. The solutions all combine single-deep racks, double-deep racks and maxi-packers to opt for a cost efficient flexible solution that can handle many types of product flows, high volume as well as low volume SKUs. The placement of space for ancillary activities in the Oatly warehouse has been conducted with their frequency of use and interconnectedness with other activities. The cost of moving equipment used for different activities has also been considered when considering a move why their placement is often remained.

The current warehouse layout can be seen in figure 4.27. It has a U-shaped material flow as both receiving and shipping docks are placed in one place. The fact that the docks are placed on one side means that the warehouse can be expanded in three directions without changing the location of the docks. The aisle configuration in the Oatly warehouse is special as the current equipment setup does not require more than two aisles per unit. The single-deep racks in the warehouse are often placed where they can fit which means that the aisle configurations among these are not unison. The current layout has insufficient space on the I/O square. Ancillary activities are placed alongside the wall of the docks or in aisles. In the current warehouse there is room for 36 pallets in the tray picking aisle. As the number of articles that are set up for less than pallet picks increase the pallet positions on level 2 in the tray picking aisle are occupied for tray picks. This is not ergonomic or cost efficient as the picks will take longer time.

4.7.1. Layout changes in the current facility

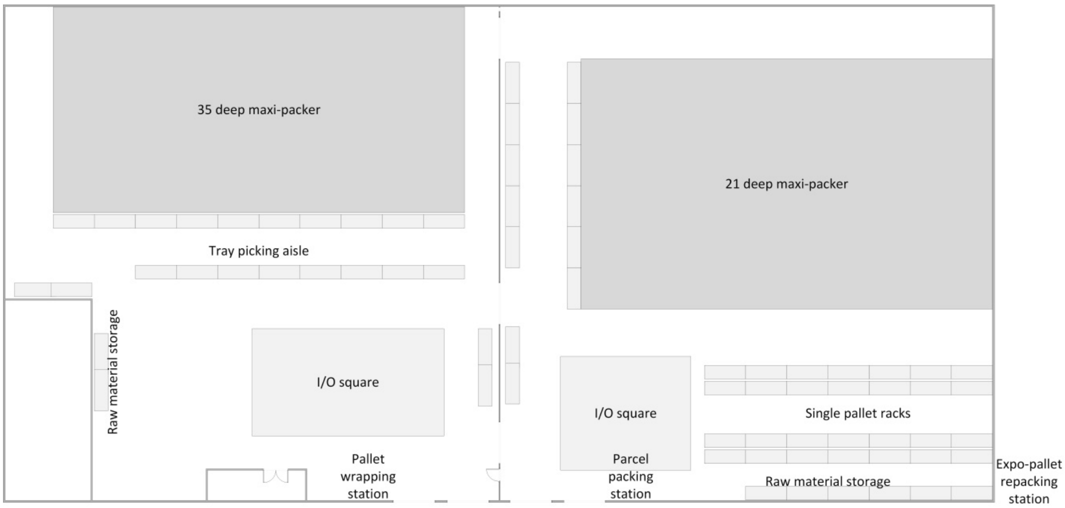


Figure 4.27. Current layout in the Oatly warehouse

The current deep lane rack system has 35 pallet positions in the chilled department and 21 pallet positions in the ambient department. The solution yields significant amounts of pallet positions being subject to honeycombing waste. Looking at the pallets in storage during a 30-day period, patterns were found that suggests that making an aisle dividing the 35-deep maxi-packer would free pallet positions. The maxi-packer can potentially be divided into two maxi-packers with 17 respectively 12-deep lanes. The changes were tested on a day that was considered to be normal. However, the data is not conclusive since data is missing for 7 lanes in the 35-deep maxi-packer though the numbers are considered to be usable as the patterns are likely to remain. Looking at table 4.24. one can see that even though 252 pallet positions are lost, changing this maxi-packer can free 195 pallet positions from honeycombing waste which yields 335 available pallet positions. In the current solution 47 % of the pallet positions are tied in honeycombing waste which is reduced to 20 % after the change.

Table 4.24. Lane depth analysis of changing the pallets in the 35 deep maxi-packer in chilled department. All numbers are in number of pallet positions.

Lane size	Total	Difference	Honeycombing waste	Available
35-deep maxi-packer	1470	0	692	140
12 & 17-deep maxi-packers	1218	-252	245	335

The same calculation for the 21-deep maxi-packer can be seen in table 4.25. The most beneficial change was to divide the 21 deep maxi-packer to two 7 deep maxi-packers. This change does not yield the same type of benefit as too many pallet positions are lost. The solution yields 28 % honeycombing waste.

Table 4.25. Lane depth analysis of changing the pallets in the 21 deep maxi-packer in ambient department. All numbers are in number of pallet positions.

Lane size	Total	Difference	Honeycombing waste	Available
21-deep maxi-packer	2184	0	575	294
2 x 7-deep maxi-packers	1456	-686	239	-56

The cost of keeping the maxi-packers will therefore be considered as the cost of double handling these pallets. As shown in table 4.26. the supplier of the maxi-packers have calculated a budget of 200 000 SEK to change the 35-deep maxi packer to one 12 and one 17-deep maxi-packer which will give an additional 194 available pallet positions. The data used to calculate the double handling cost cannot be used to determine whether or not the pallets where moved from a maxi-packer to single racks or if pallet have been moved for other reasons. After interviews and observations in the warehouse it is however certain that most of the pallets with double locations in the system were first placed the maxi-packers and then moved to a single-deep pallet rack. Most of these in turn are moved from the 35 deep maxi-packer to single-deep racks, this is thought to be due to the longer lane depth and that the product batches in the chilled section tend to be smaller. The potential savings from changing the 35-deep maxi-packer to two maxi-packers with 17 and 12-deep lanes is not possible to calculate in absolute numbers. However, the cost of double handling pallets can be used as a benchmark of how much could potentially be saved when decreasing double handling. The potential savings are not enough to reduce a fulltime employee they might not be realized. The turnover in the warehouse will increase which means that the time available for double handling today might not be in the future, with the same staffing. Consequently the operational costs can be considered to decrease when double handling is reduced.

Table 4.26. Cost of changing the 35 deep maxi-packer into two maxi-packers with 12 resp. 17-deep lanes

Layout Suggestion	Additional available pallet positions	Rack cost
Change to 17 & 12-deep Maxi-packer	195	SEK 200 000

In previous steps the I/O square has been identified as a bottleneck which insufficient capacity results in pallets being placed in aisles which can lead to safety issues and congestion. The current square size available for outgoing orders is 177 m^2 but differs from day to day depending on pallets put there for laboratory tests and the marketing departments temporary storage. The square is too small for the current way of doing operations, where all pallets ordered for the morning are put on the square during the evening shift the day before. As scheduling or changing operations is not part of this study it is merely suggested that Oatly considers benefits of allowing two pick-up intervals per day thus reducing the requirements on I/O square size. However, in the evaluation of layouts the estimated size requirements are used.

In all solutions the raw material stored in the single racks in the ambient apartment are moved to the production facility as is planned for the raw material. Expanding the square is space consuming and will require that single-deep pallet racks are demounted. In appendix B figure B.3 the layout suggestion with single-deep racks is presented. The solution reduced the number of pallet positions by 288 pallet positions. The new combined square size is approximately 330 m^2 with a capacity of 349 pallet positions, which is just sufficient for the square space requirements until 2020 for the normal scenario, see table 4.27. Additional square area will be needed in any expansion of the facility to support the operations in 2020 when all material flows are insourced.

Table 4.27. Square size requirements based on the outsourced scenarios for the normal, increase and consolidation scenarios. Required square sizes are calculated with no regard to changes in operations such as scheduling transports for shipments etc. All figures are in m^2.

	2015	2016	2017	2018	2019	2020
Normal	199	253	294	271	331	597
Increase	199	253	286	286	389	841
Consolidation	199	253	286	326	240	405

As shown in table 4.28. the solution will yield a decrease in pallet positions available, -288 pallet positions besides the raw material which will be moved to the production facility. For this reason this solution is recommended to be used as a component with other solutions.

Table 4.28. Summary of the layout suggestion expanding squares in current facility

Layout Suggestion	Pallet positions	Demounting cost	Square size
Expanding squares	-288	36 000 SEK	332 m^2

4.7.2. Planned 50 % west expansion

When the current warehouse was built in Landskrona preparations and plans were made to expand the warehouse when necessary 50 % in the direction opposite the I/O docks. This is visualized in figure 4.28. In all solutions the aisle configuration is parallel to the U-flow/circular flow in the warehouse to facilitate the material handling and reduce travel time. See appendix B for layout suggestions for single-deep racks with standard aisles, single-deep with narrow aisles and double-deep racks with standard aisles.

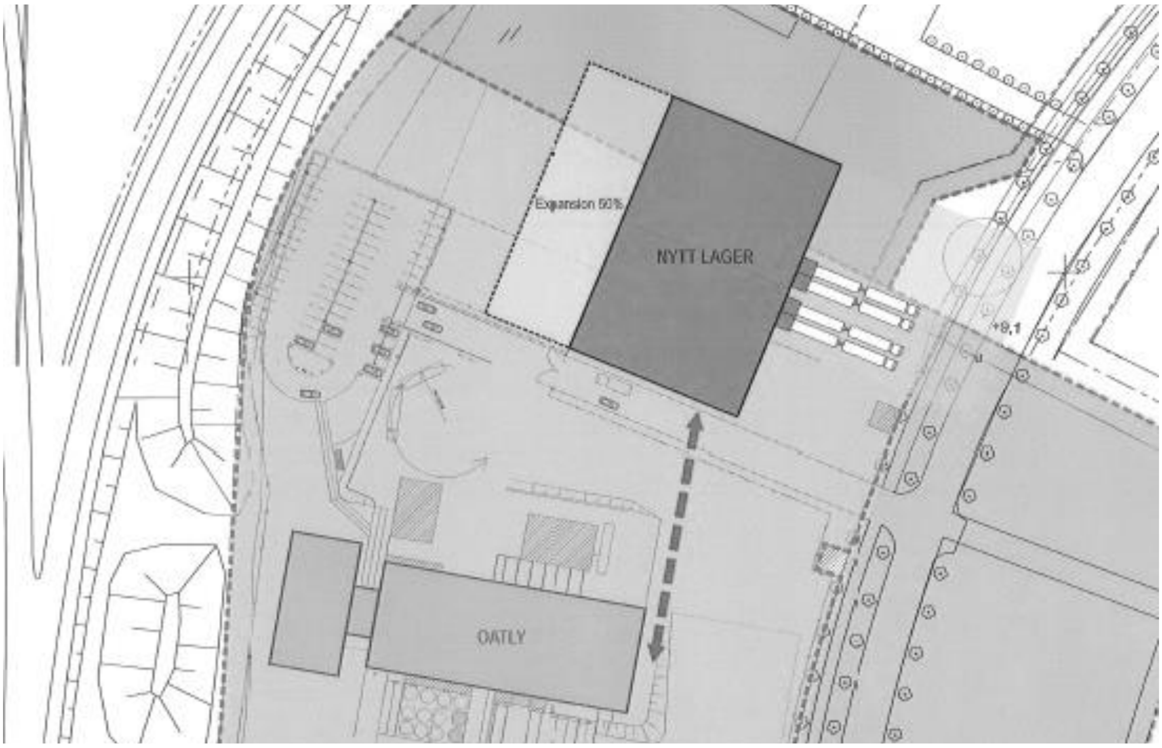


Figure 4.28. The Landskrona facility with the current warehouse is marked "NYTT LAGER" and the 50 % expansion. The building marked "OATLY" is the production facility.

In table 4.29. the number of pallet positions, rack cost, building cost as well as the equipment cost induced by the suggested 50 % layouts are shown. Single-deep and double-deep racks are the most cost efficient solutions. The cost per pallet position is SEK 259 and the same for single and double-deep rack systems while the cost for deep lane systems such as roll racks is considerably higher, SEK 3500 per pallet position. If the maxi-packers are kept in the current warehouse facility, the need for equipment setups with lower lane depth is increased to get flexibility needed for smaller flows for the product portfolio increase. The solution with the most pallet positions is the single-deep racks with narrow aisles, thereafter the double-deep racks. Estimations of the operational costs tied to the four solutions presented have not been possible to find in actual numbers. However, the narrow aisle single-deep rack solution not only requires special equipment but maneuvering in the small aisles requires precision which increases time for put-away and picking activities which increases operational cost. The roll racks requires less time for put away and picking activities than the maxi-packer as no automated pallet mover needs to be found and moved. The building cost is the same for all solutions and is calculated by using the budget cost calculated in 2012. As the inflation in Sweden has been 0 % or less during 2012-2014 this number is considered valid.

Table 4.29. Planned 50 % expansion opposite the I/O ports

Layout Suggestion	Additional Pallet positions	Rack cost	Building cost
Single-deep, 3m aisle	1524	SEK 381 000	MSEK 16
Single-deep, 2m aisle	1932	SEK 483 000	MSEK 16
Double-deep, 3m aisle	1884	SEK 471 000	MSEK 16
Roll racks 6 deep, 3m aisle	1750	SEK 6 125 000	MSEK 16

4.7.3. Further external expansion

The Oatly warehouse has been given a maximum capacity of 115 000 pallets handled per year which coincides with the forecasted amount in the normal scenario in 2020. The peak number of pallets in the warehouse is then forecasted to be just under 10 000. As the peak to average ratio is low the theory suggests that the warehouse can hold the peak number of pallets. If the 50 % expansion to the west is built the external expansion needs an approximate additional 3 500-4 500 pallet positions depending on which growth scenario is realized. The further expansion building also needs to hold the activities from the product development department as well as the marketing department, which has not been considered to fit in the previous layout suggestions. The expansion will also need a square that can hold the additional orders that will come in when all material flows are insourced.

The current warehouse is built near the border of Oatly's facility in Landskrona. Two expansions are investigated which can be seen in figure 4.29. and 4.30. They show the investigated expansions to the Oatly warehouse north and south. The south expansion in figure 4.29. is limited in size by the road and the production facility. The north expansion is currently not limited in the north direction but Oatly is currently not renting all the land under it which when the map used was drawn was planned to be built on by the municipality. The interior of the layout suggestions can be viewed in appendix B are supplied with mixes of double and single-deep racks to increase accessibility of pallets and increase flexibility in terms of reduction of potential honeycombing waste considering that the maxi-packers are kept in the current facility. In the south expansion the considered pallet mounting station has been placed in the corner closest to the production facility. It has not been considered in the north expansion. In both layout suggestions larger tray picking areas than the one currently available has been introduced. As the tray picking area essentially is the bottom level of the single-deep rack areas the number of pallet positions dedicated for broken pallets is flexible, as can be seen in the layout suggestion in appendix B.

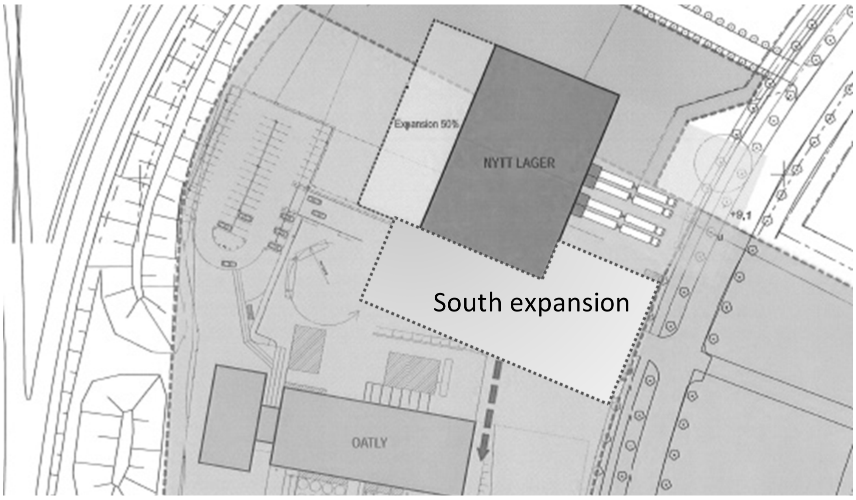


Figure 4.29. Suggested south expansion.

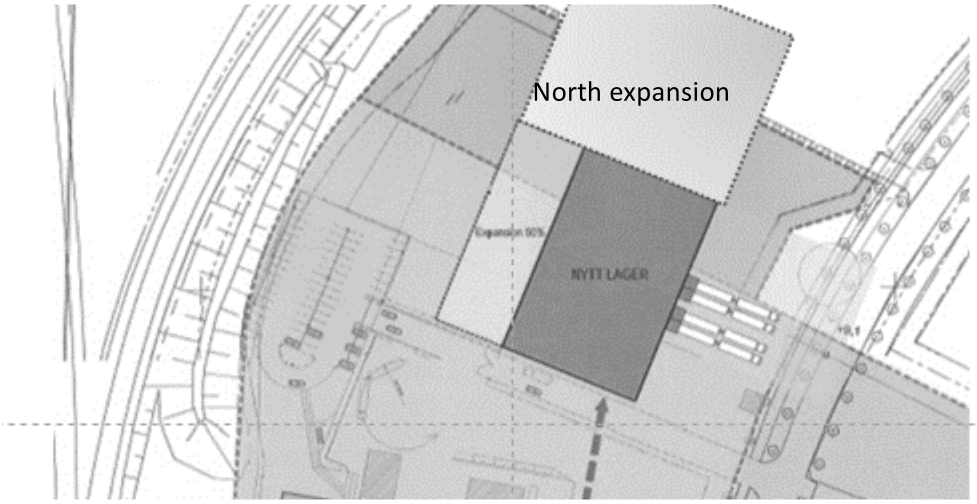


Figure 4.30. Suggested north expansion

The cost for these expansions can be seen in table 4.30. and have been calculated with the base in the cost of the 50% west expansion. The percentage of the 50 % west expansion that the south and north expansions represent have been multiplied with the considered cost of the 50 % west expansion to get the cost estimates for the suggested further expansions. The rack costs is proportional to the number of pallet positions they hold as the rack cost of single and double-deep racks is calculated as SEK 250 per pallet position.

Table 4.30. Number of pallet positions, rack cost and building cost for the suggested further expansions

Layout suggestion	Pallet positions	Rack cost	Building cost
South expansion	3360	SEK 840 000	SEK 30 070 000
North expansion	4284	SEK 1 071 000	SEK 40 700 000

Summary of Prepare Possible Warehouse Layouts	
Findings	• There are many feasible layout suggestions • The biggest cost driver is the building cost • Expansions can be made to the warehouse in three directions
Output	• The warehouse layout designs are prepared for three types of changes: inside the current facility; planned 50 % expansion west; and further expansion • The layout designs are modular and should be combined to find layout design solutions to evaluate

4.8. Evaluate Generated Layouts and Identify Preferred Solution

The generated warehouse layouts are evaluated using an evaluation table based on the decision criteria found in step 1. The evaluation table used in this project takes space requirements, operational cost and product mix and volume flexibility into consideration. The layout suggestions are presented and evaluated in this step. There are four layout suggestions that are developed and evaluated named layout 1, 2, 3 and 4. This chapter is introduced with the development of the evaluation table, thereafter the four layout suggestions are evaluated. Layout 1 is evaluated towards the current warehouse layout, and layout 3 and layout 4 are evaluated towards each other. Comparisons for layout 2 are made between a single and double-deep rack system in the planned 50 % expansion west. The preferred solution is thereafter elaborated with the potential material flow illustrated with the three scenarios developed in step 4. The preferred solution is a step-by-step expansion using layout 1, 2 and 4. Starting with dividing the 35 deep maxi-packer to two maxi-packers with 12 and 17 pallet positions deep. Thereafter the planned 50 % expansion to the west filled with double-deep and single-deep racks is recommended. Thereafter a final solution is recommended for the Oatly warehouse in Landskrona is to expand north as the most flexible solution. Thereafter a new production site will be needed which has been considered as a capacity roof.

4.8.1. Evaluation table for Assessment of Generated Layouts

To conduct an evaluation of the generated layouts an evaluation table has been developed. In column one the design criteria can be found and in column two the specific metric that will be used for the evaluation is stated. The design criteria were identified with the COO and warehouse manager at Oatly. The design criteria used are the space requirements, operational cost and the product mix and volume flexibility. The measurements are both qualitative and quantitative. The qualitative metrics are used to capture design trade-offs which cannot be calculated. These are given a grade. The qualitative measures can be considered to be criteria that can be compared objectively. For example the space requirements measurements where the absolute numbers are analyzed with the growth scenarios developed in step 4.

The space requirements measurements are all quantitative. The number of pallet positions is calculated as the number of pallet positions drawn in the layouts. However, these numbers are considered to be approximate as the ultimate facility planning with emergency exits and ventilation is outside the thesis delimitations. The same goes for the square sizes. The number of pallet positions available for tray picking is considered as the total number of pallet position that can be considered convenient for tray picking in location and level. Note that the tray picking pallet positions are a part of the total number of pallet positions.

The operational cost is a decision criterion which Oatly has rated high and has taken decisions on before in warehouse investment situations. As the warehouse does not have any WMS system the information acquired of the warehouse daily operations is limited to interviews and observations which can be considered subjective. For this reason the metrics has not been quantifiable. The measurements are double handling and material flow efficiency. Double handling is currently induced in the Oatly warehouse when no deep lanes are free for incoming goods. For this reason more lanes are considered to yield less double handling. Not having enough space in the I/O square can lead to double handling as pallets are placed in aisles before they are placed in their assigned pallet location. When pallets are placed in aisles it causes congestion and blocks pallet positions which can lead to double handling as the pallets are moved again to access blocked pallets. Double handling is also increased as the pallets are moved from production in the trailer and not moved automatically.

The material flow efficiency considers the travels of the articles through the warehouse. The material flow is based on theoretical recommendations (Bartholdi & Hackman, 2014) considered efficient if aisles are parallel with the material flow. The material flow is considered to be better if the distances in the warehouse from I/O square to pallet position is shorter. Short aisles and multiple aisles decrease the length of picking paths in tray picking which is considered to reduce picking time per route. Deep lanes reduce travel time as the aisle length a pickier need to travel is reduced. Deep lanes are considered to fulfill FIFO more efficiently as it does not require administration to keep track of individual pallets. However, accessibility of individual pallets reduces double handling while finding the right pallet for laboratory tests which would mean that deep lanes are less efficient than single or double-deep racks. Material flow is considered to be better if possibilities of congestion from both pallets placed in aisles and frequent traffic are reduced. This means that wider aisles and space to put pallets in I/O square is considered to increase the flow through.

The product mix and volume flexibility consists of four main measures; equipment setup ratio, honeycombing waste, over/under capacity and expansion flexibility. The alignment of warehouse equipment setup aims to describe the rate between deep-lane storage and short-lane storage. To keep the storage aligned with the warehouse operations the aim is to have a rack system that matches inbound as well as outbound quantities. Depending on the quantities and turnover different rack systems are suitable. For Oatly the quantities and the turnover vary among the products. To properly align the proportion between deep and single/double-deep rack systems the quantities and turnover must be taken into consideration to store the goods in an efficient way regarding both space and accessibility. In the Oatly case a maximum of 65 % of the pallet positions should be in deep racks according to the ABC-analysis from step 4.

Connected to the equipment setup is the honeycombing waste. With well-aligned warehouse equipment setup the honeycombing waste will drop thus resulting in pallet positions with high utilization. The measure is chosen as honeycombing is one of the largest issues in the current Oatly warehouse. The aim of the honeycombing measure is to detect how many pallet positions will remain unused with the layout suggestion. A low number on the honeycombing waste would be the result of an aligned warehouse equipment setup. Also connected to the equipment setup is the over/under capacity of the layout. A warehouse with overcapacity will generate excess cost while a warehouse with under capacity will generate excess costs for double handling or outsourcing. In the evaluation table the over capacity is calculated as the increase scenario peak minus the number of pallet positions available in the layout. The under capacity is calculated accordingly as the layouts number of pallet positions minus the consolidation scenario peak. The year used for the different evaluations are dependent on the potential implementation of the solution. The aim of the measure is to find in which direction the layouts' capacity is and to identify potential risks of the layouts.

The future for Oatly has been hard to forecast. Since the current warehouse was outgrown in half the expected time the flexibility aspect for the rack systems as well as the facility has been considered. The flexibility aspect is a qualitative measure that will aim to describe the layout's modularity and ability for the warehouse to expand further or decrease warehouse capacity. The investment cost is presented as a rough estimate of the building cost, rack cost and potential demounting cost. The marginal cost per pallet position is calculated as the investment cost divided by the number of additional pallet positions in the layout suggestion.

4.8.2. Evaluation of the Generated Layouts

The layout modules generated in step 7 have been combined to four top layouts which are presented and evaluated in this section. The layouts are evaluated in evaluation tables for each comparison respectively. In this part the scores of each layout will be elaborated. Each part will begin with a description of the layout presented and then evaluate the layout. The evaluations are conducted between the layout suggestions which compete for the same investments. As layout 1 is the base for layout 2, and layout 2 is the base for layouts 3 and 4 all layouts are not evaluated against each other. Layout 1 considers a redesign within the current facility which is why it is compared to the current warehouse layout. Layout 2 is compared to using a either a single-deep or a double-deep rack system in the expanded part. The nature of layout 2 is to facilitate the expansions in layout 3 and 4 thus having an additional purpose apart from adding more pallet positions. Layout 3 and 4 are compared against each other as they compete for the same investment. The scale used for qualitative grading is presented in table 4.31.

Table 4.31. Scale for the qualitative grading in the evaluation table

Scale	Comment
-	Not as good as the current solution
0	Neutral from the current solution
+	Better than the current solution
++	Considerably better than the current solution

Layout 1

Layout 1 can be seen in figure 4.31. The difference between layout 1 and the current warehouse solution is that the 35-deep maxi-packer is divided into two maxi-packers with the depths 12 and 17 pallet positions. The raw material in ambient storage will move from the warehouse to the production facility as soon as the production facility expansion is finalized which yields an increase in available number of pallet for the finished goods. The raw material in the chilled area will stay in the warehouse as it is considered complex and expensive to build an additional chilled storage in connection to the production. The square size is,, smaller than the required square space for the current needs which is close to 200 m^2 in the warehouse as presented in step 6. The square size is not presented with exact accurateness in the figure. The number of pallet positions suitable for picking is decreased to 36 when the new aisle inserted in the 35-

deep maxi-packer. It is suggested that the ambient products available for tray picking are moved to the single pallet racks in the ambient department. This reduces the number of available pallet positions for full pallet finished goods but can increase the flexibility of the solution as the product portfolio expands.

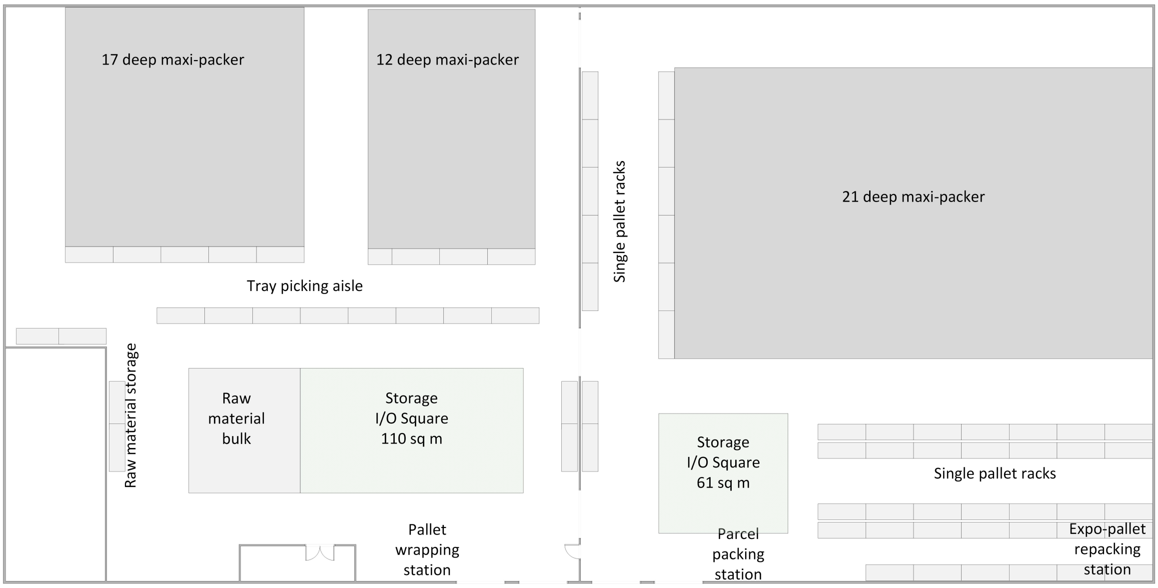


Figure 4.31. Visualization of layout 1

Table 4.32. shows a comparison between layout 1 and the current solution. The drawback with the current solution, apart from lack of I/O square space, is the vast honeycombing induced by the deep rack equipment setup. As can be seen in table 4.32. layout 1 reduce the honeycombing by dividing the maxi-packer into one 17-deep and one 12-deep maxi-packer which has yielded a better grade than the current solution in the reduced honeycombing. The number of aisles is doubled with the change and the lanes shortened which increases the material flow efficiency. Dividing the 35-deep maxi-packer leads to that the available pallet positions increase even though the total number of pallet positions is lowered. This is a result of better alignment of the rack system to the inflow from both own production as well as subcontractors. After the change, the rack system is better aligned to the inflow and outflow thus making the storage more efficient and increasing the utilization of the pallet positions. Layout 1 will not hold for the full material flow until 2020 as the number of pallet positions in layout 1 is not sufficient. Layout 1 is still recommended due to the low marginal cost of changing the racks compared and achieving 195 additional available pallet positions. Building an expansion to the facility and purchasing additional racks that will yield the available pallet positions is considered to be more costly. The over and under capacity of the solution is not used in the evaluation between the current layout solution and layout 1.

*Table 4.32. Evaluation table between the current layout design and layout 1. *The marginal cost is in this evaluation table calculated on the additional available pallet positions*

		Current	Layout 1
Space requirements	Pallet positions	4547	4415
	I/O squares m2	170	170
	Tray picking locations available	36	33
Operational cost	Double handling	0	+
	Flow efficiency	0	0
Product mix and volume flexibility	Alignment of equipment setup	0	+
	Reduced honeycombing	0	+
	Expansion/decrease flexibility	0	+
Investment	Racks and Buildings	0	MSEK 0.2
	Marginal cost per pallet position*	0	1030

Layout 2 double and layout 2 single

Layout 2 double considers an expansion 50 % to the west and can be seen in figure 4.33. The expansion is filled with double-deep racks and the inner walls are covered in single-deep racks to increase the space utilization. In the layout 2 *single* the double-deep racks are changed to single-deep racks as described in step 7. As the number of pallet positions increases, the single-deep pallet racks in the current ambient department are demounted and used in the new expansion to make room for an increased I/O square. The number of pallet positions is increased by almost 2000. The square size can be increased to 330 m^2 which is sufficient for the warehouse operations until 2019 if the export and private label flows are outsourced until then.

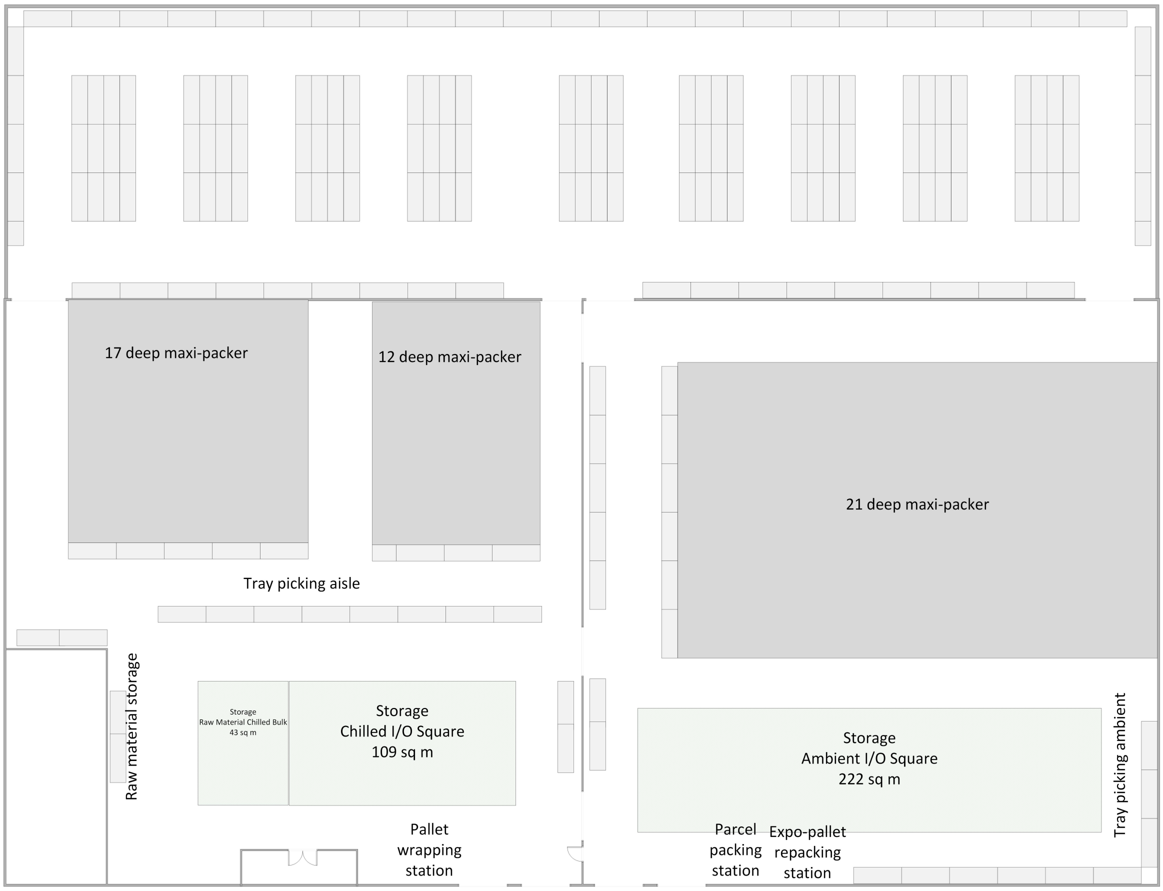


Figure 4.32. Visualization of layout 2 with double-deep racks.

The expanded area can preferably be chilled and the two variation of layout 2, to hold either a majority of single-deep or double-deep pallet racks, are compared in table 4.33. Since layout 2 is an add-on to the first layout the benefits from the division of the maxi-packer in layout 1 will carry on to the second layout as well. The difference in the number of pallet positions is approximately 360 with the highest number of pallet positions in the layout 2 *double*. Otherwise the space requirements in the layout solutions are the same. With the second layout the I/O squares are expanded to hold both the forecasted inbound and outbound goods. However, this space is not enough why there is a need to schedule shipping transports. As the I/O squares expand the single-deep racks in the current ambient department will be removed. This will not affect the operations to a large extent as the raw material will be moved to the production facility thus relieving some pressure on the warehouse. The single-deep racks in the current chilled department provide positions for tray picks to increase the number of tray picking positions the ambient products that should be available can be put in the remaining single-deep racks in the current ambient department. Depending on the convenience of the pallet position the number of pallet positions for tray picks vary but are by the authors estimated to 54 pallet positions.

Identification of pallets for laboratory tests will not require as much double handling, with single-deep racks fewer pallets might have to be moved which decreases the work load. Therefore layout 2 *single* has a better grade than the layout 2 *double*. When a smaller portion of the pallet positions is allocated to deep lane racks the warehouse can be better aligned against the pallet movement patterns. With better alignment comes a decrease in honeycombing thus the ability to utilize the warehouse to a larger extent. Layout 2 *double* has the best alignment grade as more types of racks are implemented. Layout 2 *single* consists of only single-deep racks in the expansion which is why the layout suggestion have no honeycombing. In layout 2 *double* there is a small risk of honeycombing with double-deep racks. The added pallet positions will not be sufficient for the estimated demand in 2020. For this reason the maximum over and under capacity are calculated with the increase and consolidation peaks in 2017 which is when the scenarios has yet to diverge.

One of the major benefits of layout 2 is its ability to be expanded further. Since all docks are still kept to one wall, further expansions can theoretically be made in three directions without moving the docks. Since the layout is not sufficient by itself the flexibility for further expansion is important to smoothly adapt to the increased demand. The difference in investment cost is mainly the rack cost per number of pallet position for this reason it can be shown that the marginal cost for layout 2 *double* is the lowest. Layout 2 *double* is the layout suggestion which is recommended.

Table 4.33. Evaluation table for layout 2 with single and double-deep rack systems.

		Layout 2 - Double	**Layout 2 - Single**
Space requirements	Pallet positions	5963	5603
	I/O squares m2	332	332
	Tray picking locations available	54	54
Operational cost	Double handling	+	++
	Flow efficiency	+	+
Product mix and volume flexibility	Alignment of equipment setup	++	+
	Honeycombing	+	++
	Maximum overcapacity	513	153
	Maximum undercapacity	513	153
	Expansion/decrease flexibility	+	+
Investment	Racks and Buildings	MSEK 16.7	MSEK 16.6
	Marginal cost per additional pallet position	11781	15712

Layout 3 and Layout 4

Layout 3 considers a further expansion of the warehouse to the south, presented in figure 4.34., towards the production facility. This will yield a shorter distance for the automated line from the production facility in to the warehouse which is potentially planned for the future operations. The further expansion is considered to be enough for the 115 000 pallets which is the planned roof for the warehouse at the moment. The layout suggests that the tray picking is moved into the new expanded area. The truck room and room for flammable goods are moved into the further expansion. These two moves increase the space available for the I/O square in the chilled department. The further expansion does not have any additional space dedicated for an I/O square which can be a limit of the layout suggestion.

Layout 4 considers an expansion north and can be seen in figure 4.35. Layout 4 adds on to layout 2 and is the layout suggestion with the highest number of available pallet positions. Layout 4 is modular from layout 2 and does not change any of the interior designs of layout 2 besides some single-deep pallet racks which are moved as a door into the new facility is required. The further expansion includes two additional docks primarily for the material flow and to reduce travel within the warehouse. The further expansion includes a tray picking area, like layout 3, but the one in layout 4 is adjacent to a new I/O square which is planned for smaller orders containing break up orders. As the 54 % of the shipping orders are only with break-up orders the material flow can potentially be divided to the additional ports in layout 4. The space requirement for the marketing and the product development department is places in the far corner as the travels there will be less frequent than for finished goods.

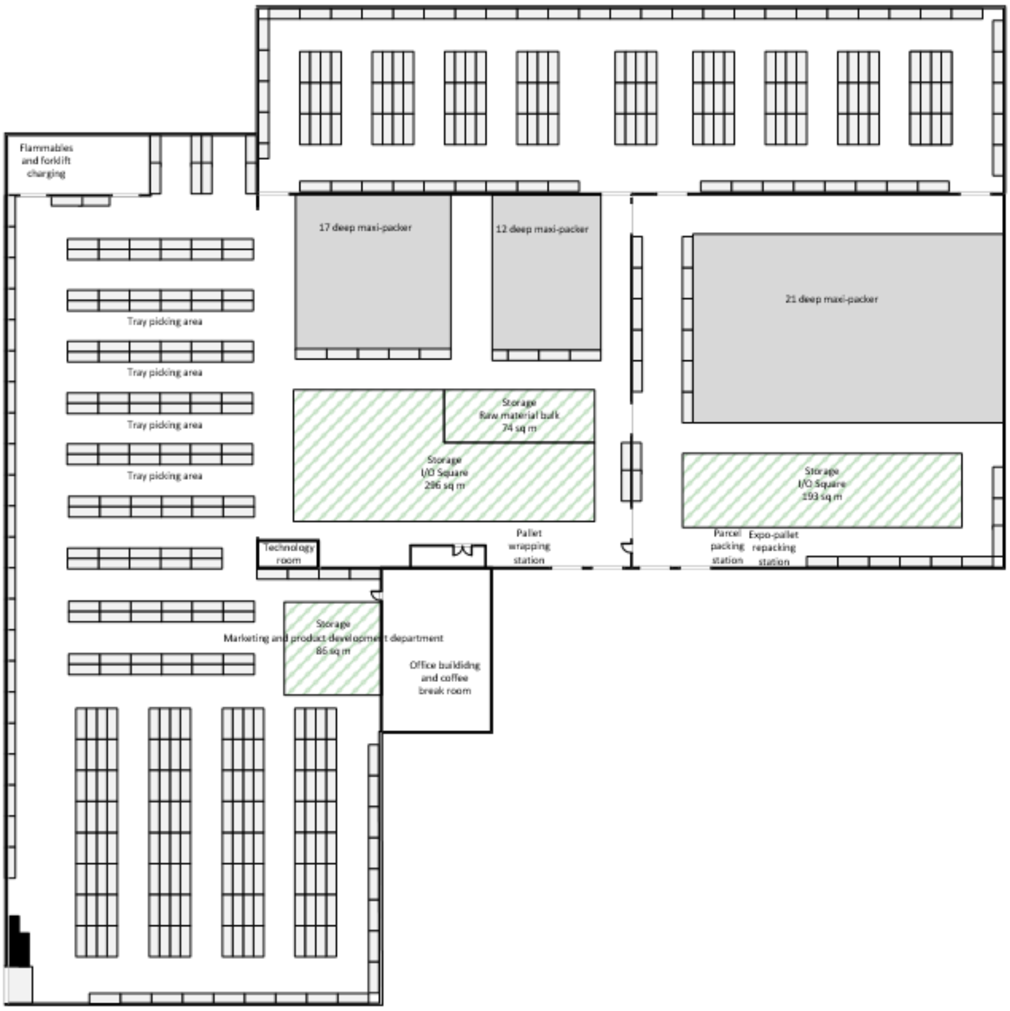


Figure 4.33. Visualization of layout 3

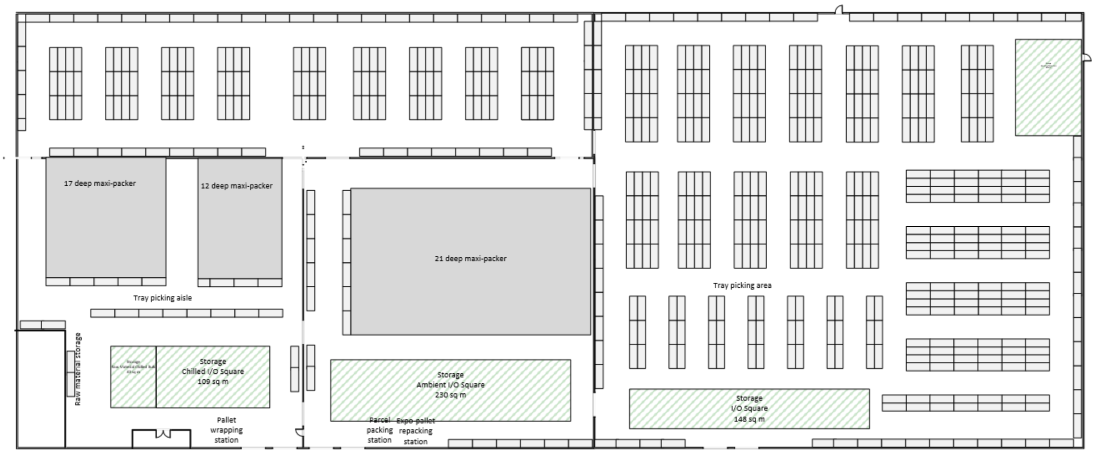


Figure 4.34. Visualization of layout 4.

Table 4.34. shows a comparison between layout 3 and layout 4. Layout 3 has a size limitation due to the production facility's placement on the real estate which has led to that the space requirements for the normal peak 2020 cannot be held in pallet positions, as a result neither can the material flow for the increase scenario be handled. Layout 3 is also the only layout that takes the potential automated lane from the production into consideration which naturally takes up space. For this reason its grade on the flow efficiency is highest. The square size in the warehouse is not as high as the 2020 requirement on Mondays which is the most intensive order day. This can however, as mentioned, be alleviated by scheduling shipping transports. The number of pallets positions dedicated or picking is flexible. As the pallet positions closest to the chilled I/O square are recommended to be single-deep pallet racks all the bottom pallet positions in the area can be used, and if the need is smaller the pallet positions can be used as full pallet storage. In contrary, major benefit of the fourth layout lies in its capacity. Layout 4 alone will almost double the amount of pallet positions thus assuring space for the Nordics, export and private label in 2020. As the future production limitation is 80 million liters, the current warehouse together with the expansion will be sufficient. The further expansion will preferably be chilled to be able to store both ambient and chilled products thus not adding a limitation to the warehouse solution. As for the I/O square size, the large expansion will also add space to the I/O square resulting in a figure which is close to the needed. If sequencing of the shipping is initiated the square might be to large resulting in waste space. This space can however be transformed to even more racks.

Table 4.34. Evaluation table for layout 3 and 4.

		Layout 3	Layout 4
Space requirements	Pallet positions	8381	10661
	I/O squares m2	409	487
	Tray picking locations available	120	142
Operational cost	Double handling	+	+
	Flow efficiency	++	+
Product mix and volume flexibility	Alignment of equipment setup	0	+
	Honeycombing	+	+
	Maximum overcapacity (2020)	1686	3966
	Maximum undercapacity (2020)	5510	3230
	Expansion/decrease flexibility	+	++
Investment	Racks and Buildings	MSEK 47.4	MSEK 58.6
	Marginal cost additional per pallet position	12362	9578

The double handling is estimated to go down in both layout 3 and layout 4 compared to the current layout design at Oatly as the longest lane depth is decreased, the number of slots and pallet positions increase and the size of the squares increase. However, if Oatly grow in the pace of the increase scenario the pallet positions needed in 2020 might be higher than the number offered by layout 3. If this were the case the double handling would increase in the same pattern as today if the warehouse operations does not change. The scenario of capacity under the demanded is of minor possibility regarding layout 4.

Layout 3 has a flow through receiving and shipping setting if the automated line from the production is introduced. This means that the flow in the warehouse is not crossing which can lead to less congestion in the I/O square and area around it. However, having more than one place for either inbound or outbound flow can lead to that the material handling equipment utilization is reduced as dual cycles are more complex to arrange. In comparison with the third layout, the fourth does not facilitate for conveyors from the production facility thus relying on transports similar of the ones performed today. A downside with the fourth layout is the inconvenience of many pallet positions as a consequence of long distances between the docks, I/O square and the pallet position thereby disturbing the flow. Therefore, there is a need to find what products that move the slowest thus minimizing the travel to the inconvenient locations. As a first step, goods connected to either the marketing department or the department for product development is planned to be placed in the far off corner of the warehouse. These goods are not moved on a daily basis which is why it will not yield increased travel times in the warehouse. The placement of the space for the marketing and the product development department is not the pallet positions with the biggest travel distance. The further expansion does include an area for the marketing and product development department which is placed outside the current office building as no pallet racks should be placed outside the office building. As there is a door from the coffee break room outside to facilitate easy access and is considered to yield extra interest from the employees which can create new solutions and a positive innovative atmosphere. The space and number of pallet positions which can be disposed by the marketing and the product development department is largest and is most flexible in layout 4.

As an addition to the proposed layout 1, both layout 3 and layout 4 aim to complement the maxi-packers with mainly single and double-deep racks. The shorter lane depth will benefit production of smaller batches by avoiding unnecessary honeycombing in the warehouse thus utilizing the space better. Apart from avoiding honeycombing the shorter lanes make the handling easier in case of tests needed to be made by the laboratory. With only single and double-deep racks a maximum of one pallet must be removed to reach the individual pallet. The honeycombing situation will foremost benefit from the increased mix of single, double and deep lane racks. The increased mix will align the equipment setup better to the operations. Therefore being able to put the pallets in the most suitable pallet racks. This will increase the availability as well as mentioned, the reduction of honeycombing.

Since most of the orders being shipped from the Oatly warehouse consists of break-up pallets more focus have been put on facilitating the ability to make efficient tray picks. Layout 4 has multiple single-deep racks with its flow leading towards a new square. The aim of the square is to facilitate building of the break-up pallets. These are later consolidated with the remaining parts of the order. With this layout 142 products are able to be tray picked conveniently and close to the square. This is also a reason for the expansion to be chilled. To make the distance from the docks to the racks as small as possible two additional docks have been placed on the eastern wall to make the receiving and put-away of goods more efficient. However, this increases the risk of inducing more complex flows in the warehouse which would require a Warehouse Management System. In layout 3 the location of the tray picking area can be considered as both beneficial and congesting. As it is close to the I/O square it reduces travel for the picker. However, it is located in the crossway from the inbound material flow to many pallet positions located in the current layout and in layout 2.

Regarding expansion flexibility layout 3 has no ability to expand towards the south or further to the west. As it is costly to move the docks expansion towards the east is not considered. The potential expansion is towards the north, like in layout 4. Layout 3 or 4 are not considered until the demand for warehouse space would grow out of layout 2 which means that there is plenty of time to further investigate the potential capacity roof preferred in the warehouse. If layout 3 is realized the decrease flexibility is limited for the Oatly warehouse. The south expansion is closer to the production facility and does not have room for additional docks which means that the expansion would be complex to rent out. For layout 4 additional docks have been placed on the same side as the current docks are placed. The additional docks are suitable for eventual over capacity where the excess capacity easily can be rented out to another company. A similar solution was considered when Oatly built the current warehouse. For even further expansions the northern expansion keep three of the walls open for further expansions. The property itself put some limitations to what extent any additional buildings are possible e.g. the highway to the west. To facilitate more efficient movements between the production and the warehouse the building can be expanded to the south in analog to layout 3. The flexibility for further expansions is therefore considered to be implementable.

The investment of the layout is highest for layout 4. This is due to that the building cost is considered proportional to the square meter size of the expansion. The rack cost is proportional to the number of pallet positions. The cost that differentiates the two layouts are the building of two additional docks in layout 4 and the movement of the truck room and the room for flammable raw material. The marginal cost of the pallet positions is lower in layout 4. Layout 4 is the recommended solution as it is a sufficient number of pallet positions for the potential material flow in 2020 in the normal scenario and has lower undercapacity for 2020.

4.8.3. Discussion regarding the preferred solution

The preferred solution can be described as a three-step approach. To align the warehouse to the current and future operations first step is to divide the 35-deep maxi-packer to one 12 and one 17-deep. Even though the number of pallet positions will decrease the amount of available pallet positions will increase partly due to less honeycombing. Since the future strategy of Oatly is towards product diversity, equipment setup as layout 1 suggests will be more in line for both the current and future operations.

The sequencing of the layouts that include expansion has been assessed against the different growth scenarios. Depending on the growth the construction of the layouts should commence at different points in time. The constraint from the number of pallet positions compared to the number of pallet positions needed is seen in figure 4.35. Figure 4.35. includes constraints on pallet positions induced by each layout. If choosing to keep all products in the warehouse i.e. no outsourcing, the current warehouse will be too small early 2016 and outgrow the second layout in 2017. With this reasoning, outsourcing of the storage for some goods is a must as soon as possible. Even the fourth layout is not sufficient for the future flow if seen to the increase scenario. However, the normal scenario is manageable within this timeframe. Layout 3 does not seem suitable for Oatly regarding number of pallet positions however since the expansion is towards the production it might seem beneficial for the operations as a whole.

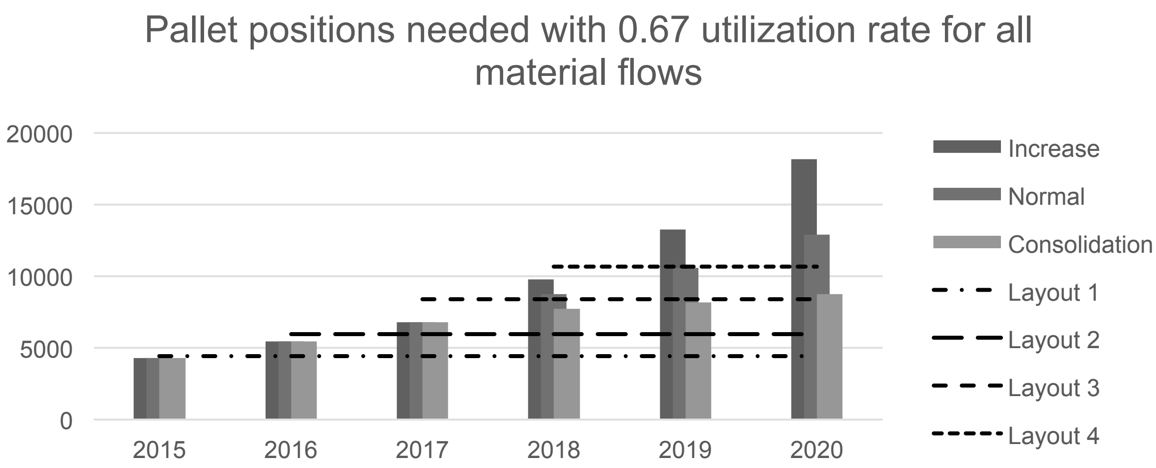


Figure 4.35. Pallet positions needed if no outsourcing of storage compared to the capacity of pallet positions for different layout alternatives.

Seen to the peak number of pallet positions needed in the Oatly warehouse the same sequence for expansions is preferred. As shown in figure 4.36., the expansion for layout 2 will be sufficient until 2017 and layout 4 until 2020 in the normal scenario. For the increase scenario the warehouse will not be able to cope with the peak number of pallets in 2020. Seen to the peak number of pallets layout 3 will just be sufficient if chosen to outsource some of the products. The major trade-off for layout 3 is regarding enough pallet positions or flow efficiency from production.

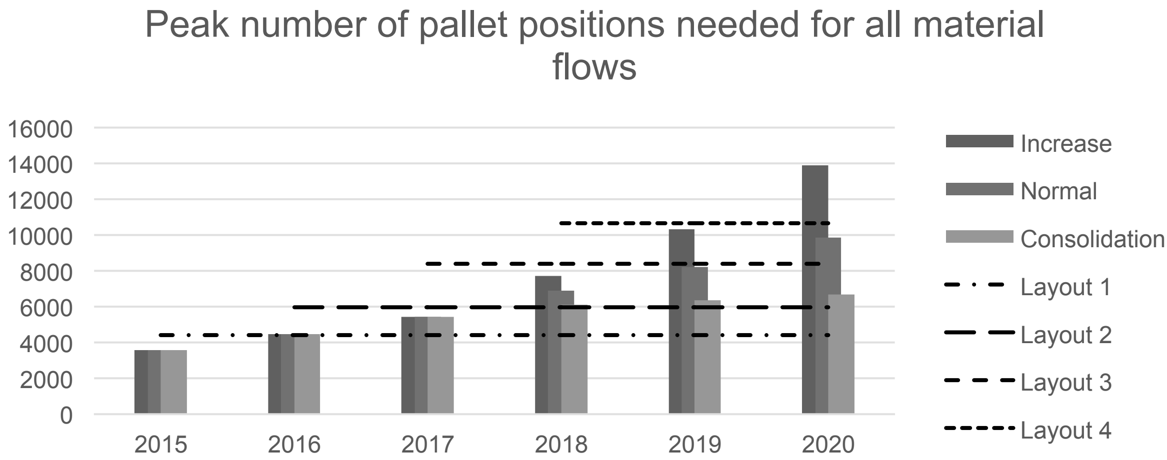


Figure 4.36. Peak number of pallets in the warehouse with no outsourcing of storage compared to the capacity of pallet positions for different layout alternatives.

With outsourcing the pressure on the warehouse will decrease, meaning that the capacity of the current warehouse will be sufficient until 2017. Figure 4.37. and 4.38. show the pallet positions needed at 67 % utilization and the peak number of pallets respectively. Both the needed positions and peak number is subject for the capacity of the different layouts. The needed pallet positions with outsourcing are not exceeding the capacity of the current warehouse until 2018. Therefore the time until 2018 can be spent on constructing firstly layout 2. The aim of the second layout is to be able to keep all Nordic goods in the warehouse. Thereafter the building of the fourth layout should commence to be able to hold all goods in 2020. This is further supported seen to the peak requirement on pallet positions. As can be seen in both figures, neither scenario will suffice for the goods handled in the increase scenario in 2020. However, this is not an issue since the current production limit is at 80 million liters demanding approximately 10 000 pallet positions in average. For all three scenarios the expansions in layout 2 and 4 are needed. Only in the consolidation scenario the third layout alternative might be of interest to avoid having too much space available and therefore align better to the demand on pallet positions.

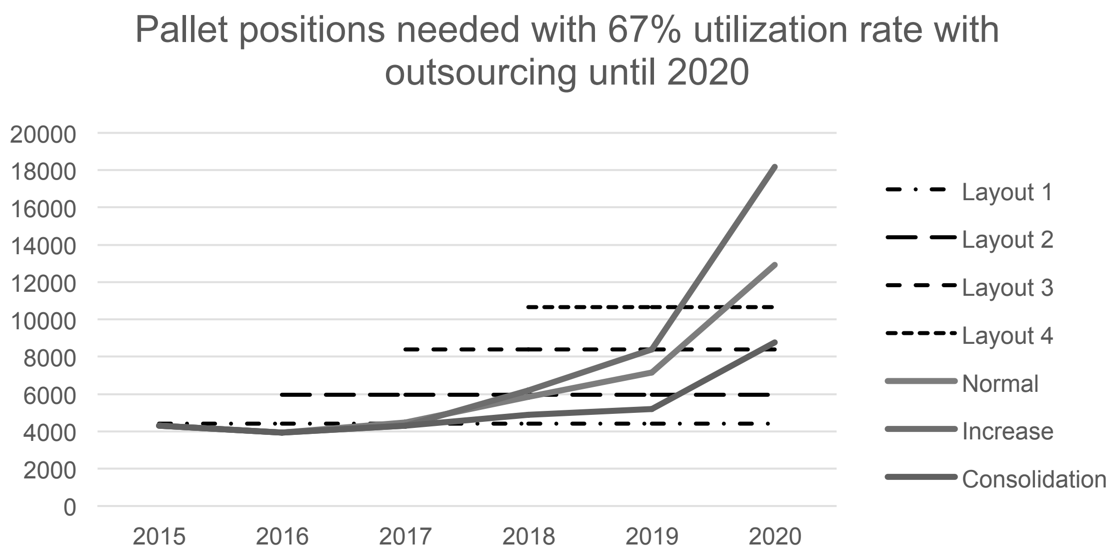


Figure 4.37. Pallet positions needed with utilization rate of 67 % and outsourcing of goods compared to capacity of pallet positions for the different layouts.

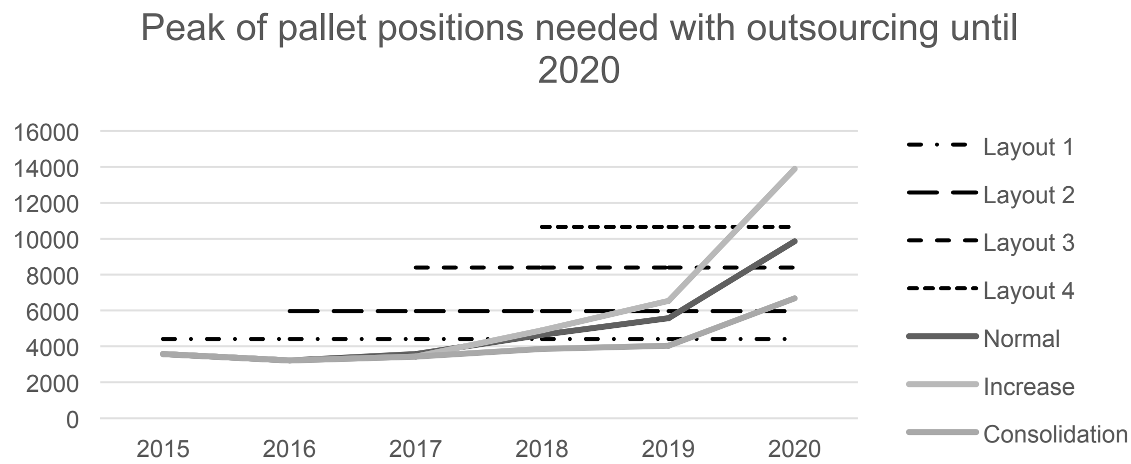


Figure 4.38. Peak number of pallet positions needed with outsourcing of goods compared to capacity of pallet positions for the different layouts.

Figure 4.39. and 4.40. show a simple time line for suitable times for introduction of the different layouts regarding maximum amount of pallets and the 67 % utilization rate scenario respectively. Both cases assume that export and private label goods are outsourced. There are no large differences between the cases. Layout 1 should be introduced as soon as possible to align better with the current in- and outflow. Layout 2 should be introduced in 2017 to avoid the risk of having to high utilization rate. With the same logic layout 4 should be introduced around 2018. Layout 3 is not part of the timelines due to the fact that the number of pallet positions provided by layout 3 is not sufficient for the demand in 2020. However, layout 3 might be suitable if there is interest to narrow the gap between the production site and the warehouse.

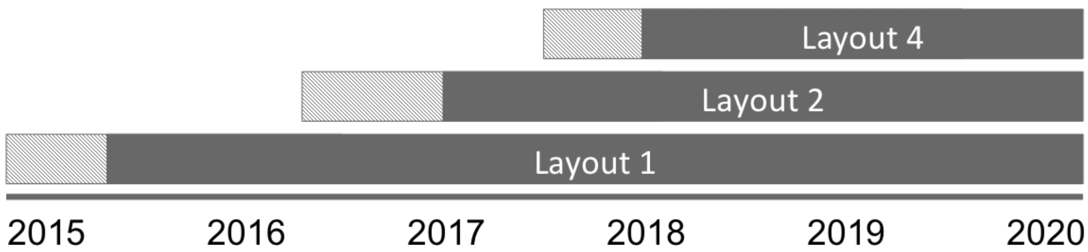


Figure 4.39. Timeline for the build of the layouts to manage a 67 % utilization rate.

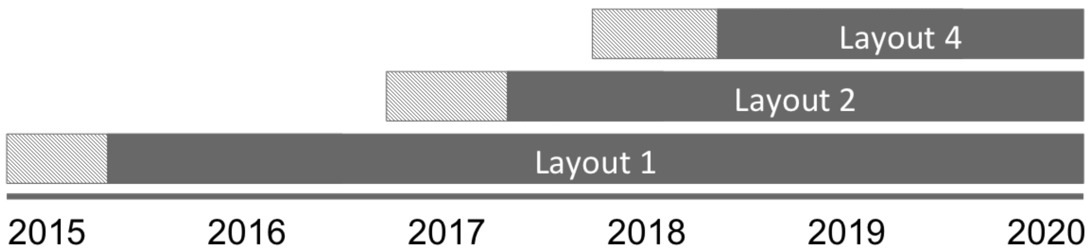


Figure 4.40. Timeline for the build of the layouts to manage the maximum amount of pallets.

Summary of Evaluating Generated Layouts and Identify Preferred Solution	
Findings	• A sequencial solution fit the demand pattern
Output	• Layout 1 should be introduced as soon as possible • Layout 2 should be introduced during 2017 • Layout 4 should be introduced during 2018

5. Analysis of the Warehouse Layout Design Framework

This thesis is aimed towards warehouse layout design in fast growing companies which has affected the aspects considered. The aspects that have been identified which are connected to flexibility for volatile demands will be the focus in this analysis. The chapter will begin with an analysis of the warehouse layout design research connected to aspects considering growth and flexibility. The warehouse layout design literature also consists of many frameworks which are also considered in the first part. Thereafter usability and refinement of the developed warehouse layout design framework is investigated. Focus in the latter part is on how the application at Oatly affected the framework and what can be considered useful in other cases.

5.1. Analysis of Reviewed Literature

Warehouse design is an expensive and is considered complex activity why it requires rigorous analyzing to find a solution that will balance investment costs with the operational costs the design will incur. Out of the frameworks reviewed only one includes considering future demand, including forecasting as a step in the layout design process. If the future demand expectations on the warehouse are not considered as a part of the design process, the warehouse might be outgrown faster than expected or have overcapacity for several years. The outgrowth and overcapacity will generate additional costs for adaption; expensive hastily built new buildings and redesigns. In the Oatly case the current warehouse was outgrown in half the calculated time. The new management set a new corporate strategy just one year later, which included a more diverse product portfolio and increase in marketing. The changes lead to that the demand on the warehouse shifted heavily. These kinds of demand changes are hard to predict and underlines the importance of understanding the growth patterns in demand and how the corporate strategy is likely to develop to create a sustainable warehouse solution. Facing an uncertain future, both growth and decline scenarios, make flexibility a key aspect when designing the warehouse. The frameworks reviewed do not take flexibility into consideration which demands accurate forecasting. To manage the risk that the forecasting could be inaccurate, flexibility in the storing activity can be added. This could affect the later steps of the development process regarding choice of racks and equipment.

The frameworks regarding warehouse development found in literature mainly have their background in theoretical models. As a consequence, their starting position for the warehouse design is an empty rectangular without previously set conditions such as an existing facility or previously set operational processes and systems. The frameworks often have one specific niche towards either minimizing travel time for pickers or minimizing floor space needed. However, many researchers within the subject conclude that a warehouse design needs to take all these aspects into consideration to avoid a suboptimal solution. Additionally, further research with practical applications on these theoretical frameworks is scarce and therefore the connection to practice can be unclear and the frameworks can be hard to apply without alterations and experience. The lack of practicality in the frameworks can be divided into three parts; expected future demand, redesign and being too general.

The second gap found for practicality, redesign, regards the fact that reviewed frameworks does not consider the current facility and warehouse layout design. In a few data gathering plans information about the current warehouse design was requested. However, how and when to use the information about the current layout is left to the practitioner. When designing a warehouse many companies are changing or expanding a current solution. Either considering a current facility in connection to their current area, or potential expansions to their current solution. To demount and change a current warehouse layout incur high costs which are not taken into consideration in current layout design frameworks. Warehouse design complexity is partly due to the vast number of feasible solutions to consider. Considering redesign in a warehouse layout design process can be considered to add complexity. The increase in complexity origins from an increase in the number of feasible alternatives and additional constraints affecting the solution. Both of these scenarios will increase the number of trade-off situations where the cost of demounting or keeping a current solution needs to be considered. To be able to redesign in a cost efficient way, flexibility can be designed for the warehouse layout design if cost of demounting and rearrangement are kept in mind. With long term growth in mind modularity in the solution regarding both real estate and equipment setup can be beneficial for the alignment of the warehouse to the overall operations. With certain long term growth and stable corporate strategy a partly suboptimal solution can be beneficial when new modules are added to the current structure over time.

The fact that most frameworks reviewed are too general can have an impact on the applicability of the frameworks. Currently the research on warehouse design is rather scarce and the aim of the theory is often to discover the warehousing layout design phenomena as a whole or in very specific and/or extreme cases. This means that frameworks reviewed to a large extent are generic in their concluding remarks, partly due to the amount of situations, backgrounds and premises affecting a decision regarding a warehouse design in reality. Not considering redesign is connected to the generality of the frameworks. As an example, some of the reviewed frameworks argue for the usage of simulation to evaluate and find the optimal solution of layout structure and facility planning. However, their starting position for the warehouse design is an empty, rectangular real estate with undefined measures. The solution generated can thereafter be a pattern for a rack system which is suitable according to a few chosen preconditions. Generating a solution that is claimed to be generally applicable for warehouses, only if the warehouse has the same proportions and demand patterns as the simulation model. As a consequence the result is not always applicable in practice. Connected to the generality is the purpose of the design changes. In the Oatly case the honeycombing is the main issue whereas picking efficiency can be the focus in other projects. Due to the generality there are no main issue addressed in the theoretical frameworks thus leaving connections to e.g. picking out of the steps developed.

In the frameworks reviewed one or more steps relied heavily on experience leaving no guidance for the user or practitioner. The frameworks developed in case research can also be hard to apply in new projects since most are made *ad hoc* and alterations are made to make it suitable for the company in focus. The *ad hoc* approach is in line with projects within warehouse design where many projects differ from one another in one or more aspects. These differences can make to general or undefined models or frameworks hard to apply. As a consequence the demand for experience when developing warehouse layout is high. The experience partly needed in the early steps of the development to be able to identify the key requirements and must-be characteristics of the warehouse. These characteristics are not excluded to more obvious aspects such as the required amount of pallet positions but consider more subtle characteristics such as changes in future operations in product flow as well. Framework steps aiming to get an understanding of the corporate strategy can be more helpful for people with large insights within warehousing and operations or supply chain management as a whole but less for newer practitioners with a more limited experience of the activities outside it. With more specific procedures in such steps that provided in the reviewed frameworks, inexperienced practitioners might be able to grasp the research and use it more hands-on. Experience is also considered to be valuable to reduce the time needed in the design process. The amount of layout alternatives can be reduced quickly by an experienced practitioner. To avoid suboptimal solutions trade-offs must be made in the design process. When qualitative factors are involved in these trade-off situations, such as ergonomics and workflow dynamics, experience great impact on the quality of the analysis of its pros and cons.

The reviewed frameworks all follow a waterfall type of model where one step forms the base for the next and so forth. However, researchers argue for the complexity in warehousing derived from the linkages between the warehouse activities. Further, warehouse design tasks are hard to reduce to isolated sub-problems thus adding importance to a holistic development process. The design of a warehouse layout does not only concern the warehouse operations itself but also concerns production as well as sales. The warehouse layout, especially the rack system, is highly dependent on both production batch sizes and the sales characteristics for efficient handling and storing. The development should therefore be iterative and striving towards a global optima for the whole warehouse operation thus challenging the waterfall types of models.

As the developed warehouse layout design framework has its base in reviewed frameworks developed for warehousing design some of the issues identified can be found in this framework as well. As it is refined and developed through a single case study alterations are made to make it suitable for the company in focus which means that it can be hard to apply in new situations as it is as some steps might be too specific and others to broad.

5.2. Assessment of the Warehouse Layout Design Framework

The development of the warehouse layout design framework has its base in existing frameworks found in literature. The developed framework has used and adapted many steps found in the reviewed frameworks to be more suitable and directed towards companies experiencing volatile or fast growth. The uncertain growth is a symptom of fast growing companies puts higher pressure on some steps of the design process than others. With the additional pressure on warehouse objective and on forecasting the usability of the warehouse layout design framework aims to be increased from the reviewed frameworks. Both of the steps regarding these aspects have more attention in the developed framework than what they have in current literature mainly due to the high costs connected to changing a warehouse.

Benefits from the increased focus on flexibility are not necessarily only gained by fast growing companies. All companies operate in a more or less uncertain environment which means that there is always a risk for changes in demand on the warehouse. The business climate is increasingly competitive why changes in corporate strategies can become relevant for companies who are not considered fast growing companies. Potential decreases of warehouse operations require as much or more flexibility and risk assessments as potential increases in demand.

The structure of the warehouse layout design framework consists of two parts. The first part covers the warehouse objective, strategy and demand on the warehouse and second part covers the facility design including equipment setup, space requirements and layout. The main mission of the first part is to get an overlook of the warehouse operations and what to expect in the future both regarding demand but also activities performed in the warehouse. The sequence of the two parts was chosen mainly based on the structures found in the reviewed frameworks. Rouwenhorst et al. (2002) has stated that it is important to consider warehouse design with a top down approach. Using the top down structure was further motivated by the found need to align the facility planning with the corporate strategy and growth expectations from the beginning. With a clear view of the current situation and what to expect in outcomes in the future demand an aligned facility design is easier to develop. With the demands on the facility set, the second part focuses on developing a layout that considers all requirements elaborated in the first part. The final framework and the placement of the steps has been developed iteratively between literature and the Oatly case to find the most logic flow.

In this thesis the warehouse layout design framework have been used with a top-down approach starting in the objective and ending in a layout suggestion. However, iterations between step were made on the way. Applying the warehouse layout design frameworks to the Oatly case showed the importance of a well-formed warehouse objective. During the time of the study Oatly developed new forecasts of future scenarios and investigated several supply options that affect the warehouse which is why the first step was revisited several times. Its importance is underlined by the fact that all steps have its pedigree in the warehouse objective. The waterfall analogy found in current literature is therefore not always suitable. The first part of the framework has a more fact-based and qualitative nature. For this reason these steps can be started somewhat simultaneously and will yield understandings from each other. For the second section of the developed framework iterations are especially important since the equipment setup and the layout are dependent of decisions for one another. When cost is added as a dimension in the evaluation step previous decisions are questioned and additional trade-off situations emerge.

Compared to the reviewed frameworks the warehouse layout design framework provides additional focus on issues related to growth and strategy. The company's corporate strategy plays a crucial role in assessing the company growth, and by that, the warehousing objective. As part of the warehouse objective comes strategy regarding both the company as a whole as well as product strategy. For strategy regarding the supply chain it stands clear that Oatly does not have ability to operate solely on its own terms. An example is the division of power within the supply chain. The major food retail chains have most of the power in the network which puts pressure on the Oatly warehouse to adapt. This further underlines the need for flexibility within its warehouse operations. In other industries the power balance might be different. The history of the current Oatly warehouse clearly shows what impact the product portfolio strategy have on the warehouse operations. With a clear product strategy in mind the operations can be as aligned as possible including the warehouse layout.

The mapping of warehouse has its main purpose as defining the as is situation of the warehouse operation and identify bottlenecks with the layout. The reviewed frameworks do not include any mapping step of the storage process in the warehouse. However, the overall material flow is often considered to facilitate layouts planning and dock placements. In the Oatly case the mapping of the storage process identified double handling due to the deep lanes in the current equipment setup.

In the Oatly case the finding of storage handling unit was easy to conduct since goods is both shipped and received on pallets. In other cases this might differ why the focus and additional analysis in later steps might be required. For a storage with a majority of orders including pieces, more attention will be brought to picking and grouping of articles for as efficient operations as possible. This step can seem small is important for the steps later on due to its effect on handling and equipment. To assure maximum efficiency careful considerations of the future handling units should be made. In the Oatly case the pallets are the main storage unit and therefore the unit to keep track of. The fact that trays are picked to be put on pallets is why trays are not accounted for then designing the Oatly warehouse. In warehouses with several handling units should be done in more dimensions to cover the warehouse activities in a comprehensive way.

The main aim of the forecasting lies in its ability to help secure an adequate warehousing solution for the future demands. As part of this, the growth expectations must be assessed. The growth should not in this case only regard volumes such as number of trays and pallets but again connect back to the portfolio as a whole. In this case study the forecasting of expected demand was complex since Oatly is growing rapidly in a fast growing market. Different scenarios were formed to analyze how the warehouse was affected by lower and higher outcomes than expected. This was found to be valuable by the decision makers at Oatly since the expected demand for Oatly is uncertain and sales have historically mostly exceeded the forecasts made. The forecasting is important but can be hard to evaluate and estimate. Forecasting can be disintegrated into rich amounts of indicators and data points.

The planning of space requirements does not differ from the much from the functional specification conducted in many of the reviewed frameworks. The addition in this thesis come from the directed focus on future activities and the space these activities need. The space requirements form a minimum for the real estate. In the Oatly case the future line from production must be calculated for to suit the upcoming operations.

When considering the equipment setup the warehouse layout design framework provides increased focus on flexibility and alignment towards the company. The backbone of this step is the warehouse object, storage handling unit and the forecasted demand. The input put clear demands on the equipment setup needed. In the Oatly case the FIFO-policy is required due to the perishability of the goods. In this thesis much focus have been shifted towards solution being able to handle perishable goods thus limiting the scope. The step as a whole will however work with any storage policy. The sole handling of pallets in the Oatly warehouse have the same effect on the equipment setups as on the thesis in analog with the FIFO-policy.

Due to the amount of alternative solutions for most decisions in warehouse design, some steps in the warehouse layout design framework can be considered vague and their applicability will rely on the experience of the user. This need for experience is especially shown in the preparation of possible layout step where little guidance is provided.

In the Oatly case, simulation could have been used to evaluate layouts and to find a solution which would minimize the operating costs in the warehouse which was one of the most prioritized design criterions. However, the timeframe of the project made this infeasible. Double handling of pallets are a main driver of non-value adding operational costs in the warehouse today. Therefore equipment setups that reduce double handling has been considered to reduce operating costs. If developing a layout where pick efficiency and long travel times had been an issue due to long routings a simulation model would provide useful information. Then output of the information could potentially make up for the long development time of the simulation models.

6. Conclusions and Further Research

The aspects to be considered in warehouse design can be divided into two types; aspects that are connected to the warehouse role in the network and its placement in the supply chain and aspects that are connected to the warehouse layout. This study has found that aspects related to future demand expectations and future operations in the company. Other aspects that are missing in today's research on warehouse layout design which can help to ensure a cost efficient solution are the impact that the current warehouse solution has on the final solution. Connected to the current solution is the aspect of flexibility for expansion or decrease in the generated layout designs. A warehouse layout solution can be generated by using a framework which takes these aspects into consideration. The warehouse layout design framework developed and refined through this study is divided into two parts and has eight steps. In the case study was found that the framework is well applicable in the Oatly case and can therefore be assumed to be applicable in other warehouse layout design projects with fast growing companies. However, experience still has a large impact on the result primarily due to the vast amount of alternative feasible solutions present when preparing a warehouse layout design. Further research should therefore be directed towards finding a procedure within the layout design phase to make the framework less relying on experience. The two research questions are thoroughly answered below.

6.1. Conclusions

What aspects should be considered when designing a warehouse layout to ensure that it is aligned with the company growth expectations?

Aspects that are beneficial to consider when designing a warehouse for a fast growing company which are not commonly found in today's research are aspects related to the volatility of growth expectations and future operations in the warehouse. The warehouse layout design's need for flexibility in capacity is highly affected by aspects such the growth expectations effect on demand patterns, the warehouse power and placement in the supply chain network.

Requirements regarding increase of capacity in the warehouse are largely determined by the company's plans of expansion. The company's plans of expansion and expended increase in sales on current markets are the foundation of the demand planning for the warehouse. The profile of the demand on warehouse activities is affected by the company's product portfolio's size and mix. These portfolio characteristics are often a part of the company's value proposition and clues of how the product portfolio is likely to change over the timeframe considered is therefore often found in the corporate strategy. How increase in demand in the warehouse affects the different warehouse activities differ. In this case study for example the volume of sales were likely in increase in a fast pace. The number of orders was to stay the same instead it was the size of the orders which were likely to increase according to the supply chain coordinators plans and based on historical data at the case company.

The power of the warehouse in the supply chain network can greatly affect the warehouse as the freedom to schedule transports or determining minimum order quantities is affected by it. The placement of the warehouse in the supply chain network is important when considering the need for demand flexibility. The longer the distance from the end customer the more significant is the demand volatility often called the bullwhip effect. With larger differences in demand volatility comes an increased need for space to enable the warehouse to operate cost efficient, by reducing the need for double handling, fulfillment of sufficient amount of orders, at all times. Postponement is an increasing trend in supply chain management which increases the number of activities or services are performed in a warehouse. This increases the need for flexible space in the warehouse that easily can be rebuilt to suit a new activity or warehouse service such as repacking, repairing or kitting. The three main types of warehouses are production warehouses, distribution warehouses and contract warehouses. The different types of warehouses are not equally likely to start the different activities. The layout design is affected by the warehouse type as the placements and size requirements of activities as well as equipment setups are likely to differ.

A warehouse layout design is fixed by nature as it is a considerable investment for a company and is costly to change. Changing a warehouse layout often requires down time of the warehouse which can lead to the need of a production stand still or procurement of 3PL services. Both of these solutions can be as expensive as the new warehouse layout and increases the complexity of changing the design. For this reason aspects considering the current layout design should be considered when redesigning a warehouse layout to be sure that the most cost efficient solution is found. The case in this study has shown that the preferred solution is not always the solution which is the most in line with the activity profile in the warehouse. The preferred solution is the one that is most cost efficient in terms of investment cost and operational cost. Considering smaller changes the current layout design, expansions that do not require a rebuild of the current solution and changing the current equipment setup rather than investing in new can lower the potential investment cost of the warehouse. The complexity of changing a warehouse layout solution also illustrates the importance of aspects considering future expansions or decreases of the warehouse. For a fast growing company the demand is often uncertain. The opportunity to expand or decrease a warehouse layout design without changing the current layout design increases the company's ability to operate more flexible. For this reason modularity of the warehouse layout design can be considered when the layout is generated and evaluated.

Layout designs which are more proactive and flexible for volatility in capacity demand can be generated by considering these aspects. If flexibility to scaling of warehousing capability is considered when generating layout designs the final solution can be cost efficient for a longer time. Having planned for several scenarios can also reduce impact of disruptions and decrease reaction time to change the layout design which can keep the company competitive.

Additional focus on primarily forecasting, flexibility and objective of the warehouse can help practitioners in many ways. It will provide good knowledge of the future supply and demand which is a prerequisite to align the warehouse with the operations. As a result it can be more cost efficient. The cost efficiency from better alignment does not only lie in the daily operations but also regards efficiency in the investments being made. Constructing a warehouse with the future in mind can help avoid unexpected future investments needed to be made. These investment costs are often high since unplanned expansions and rebuilds are more complex than first-time builds.

If the demand is unsure focus should lay on making rearrangements as smooth as possible. By adding the flexibility for future changes in demand to the warehouse layout design further expansions of the warehouse can already be prepared for. The flexibility will help companies that are facing an insecure market with needs for changes in the product portfolio regarding both produced volumes and the number of products. Expansions are affected by the product volumes while the equipment setup is affected by the number of products.

How can a warehouse layout design be generated that ensures flexibility and ability to handle future warehouse operations?

To ensure that all relevant aspects are considered in a logical sequence when designing a warehouse layout, frameworks can be used to generate suitable layout designs. The warehouse layout design framework developed and refined in this study has been developed through a step-wise categorization and cherry picking of frameworks found in today's research on warehouse layout design. The final warehouse layout design framework presented in figure 6.1. is made of two parts, an initial part aiming to define the overall requirements on the warehouse and one part focusing on the planning of the facility. Benefits of the two-folded structure are mainly the clarity resulting from a solid background and requirements specification and the simplicity in developing warehouse layout design when the requirements are identified. By stepwise determination of the key factors such as required pallet positions, product requirements and product limitations, the amount of possible warehouse solutions decreases. By delimiting the number of feasible solutions for the design early in the development process deeper analyses can be made on the remaining alternatives thus resulting in a better founded final solution. The fourth step, forecast and analyze expected demand, is located as the last step of the initial part of the framework. The step plays an important role in the framework as it ties together the requirements from the warehouse objective, findings from mapped warehouse activities and storage handling units identified. In the step future scenarios for the chosen time frame are developed to find a solution that is flexible to several potential scenarios. The forecasting is further connected to step six planning primarily to ensure enough capacity in the ancillary activities and any future operations. Therefore it is important not only to find the demand on the warehouse from a warehousing point of view but from a whole supply chain network perspective prior to the forecasting. If the demands from sales, marketing and production are not aligned with the services that the warehouse provides high costs can arise.

Consideration to the current setup, redesign of a warehouse, was found to be missing in the frameworks reviewed. They often assumed an empty, rectangular warehouse of an undefined size that could be filled with whatever equipment setup was found suitable. A layout redesign is more complicated than a new layout design as the change of a current solution creates additional economic trade-off situations. Demounting racks incur high costs in addition to the investment and building of a new rack system. In the warehouse layout design framework the current warehouse solution is concerned in all steps of the second part of the framework to ensure a cost efficient solution. Benefit analysis of possible adaptions of the current system are analyzed before deciding on a new layout design or equipment setup. The case in this study where the refinement of the warehouse layout design framework has been conducted was made for a redesign process. The parts of the steps in the framework considering the current solutions has been developed through empirical work rather than from theory reviewed. The redesign alterations in the framework are most evident in the selection of equipment setup and preparations of possible layout generations.

The warehouse layout design framework has a clear base in frameworks found in literature. The additional focus points on forecasting and the current equipment setup are added to provide support to enable development of cost efficient and flexible solutions for the time frame considered. The warehouse layout design framework is designed to be more comprehensive and suitable for companies facing an uncertain future, for example fast growing companies, in their process of a design and redesign of a warehouse layout.

The main benefit of the warehouse layout design framework lies in its structure. By following the framework the important aspects will be covered a logic way. Requirements from the supply chain network and purpose of the operations are identified in the first part of the framework. The second part of the framework uses the requirements from the first part to develop a warehouse layout design aligned with the company's future operations. The alignment affects the efficiency of the design process positively in terms of minimizing the possibility of expensive rebuilds.

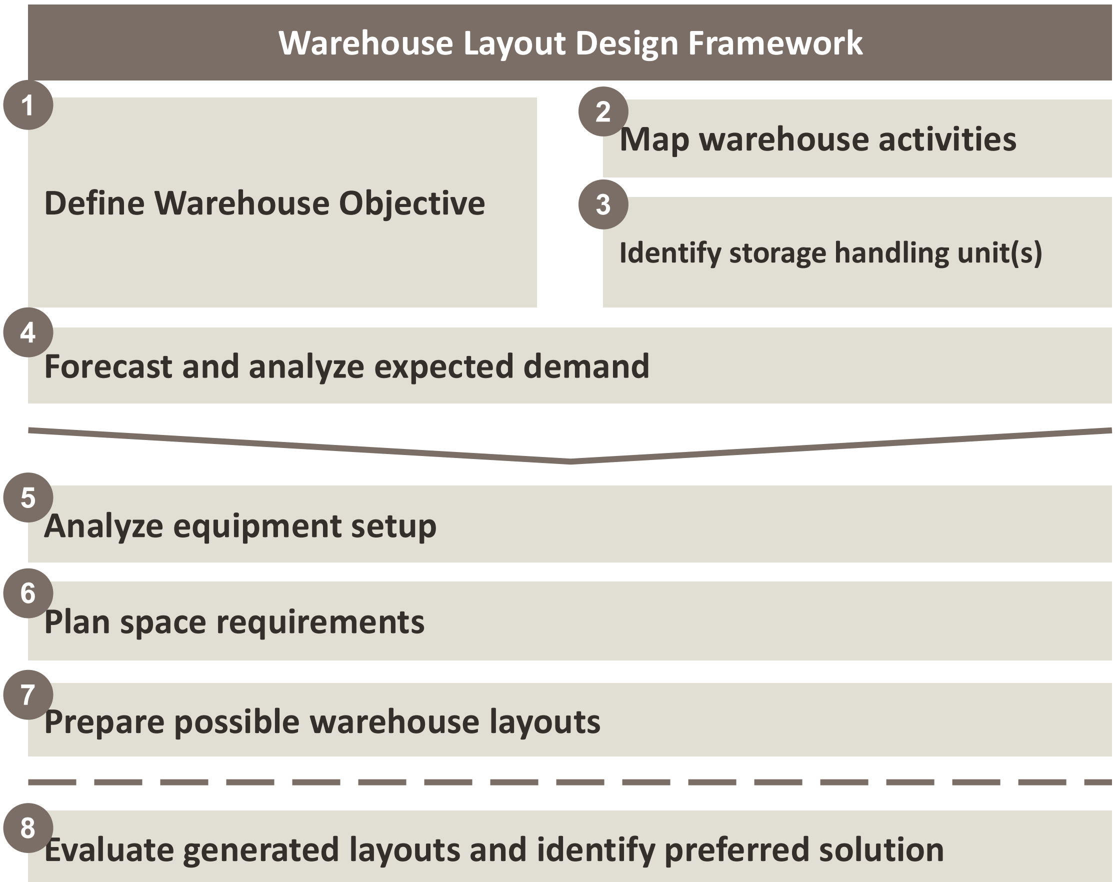


Figure 6.1. Simplified visualization of the warehouse layout design framework

6.2. Further research

The scope of this thesis is warehouse layout design for fast growing companies. During the study aspects relevant for warehouse layout design in today's research has been reviewed. The aspects relevant for warehouse layout design for fast growing companies has been identified and the warehouse layout design framework has been developed. The framework has thereafter been used and refined at the case company Oatly. To increase the generality of the framework and the validity of the found aspects, the framework should be used on more cases at companies with similar issues. With additional studies the aspects could be further refined regarding both number of aspects, sequencing order and their importance for warehouse layout design. The aspects found to be important in this thesis are comprehensive but sometimes not exhaustive. With more case studies, focus can be put on verifying and validating the aspects to find the relative importance and contribution to a warehouse design project.

The framework developed in this thesis has mainly been refined with pallet handling in mind as the case company in close to a unit load warehouse. Future research should therefore be aimed towards other handling units and types of warehouses to get a better understanding of the usability of the framework. Especially interesting can warehouses containing fast moving consumer goods be for investigation. The main design criterion for these kinds of warehouses are focused on operational efficiency in terms of routing of picking paths and that have more developed picking strategies and picking policies. The intersection between picking strategy, layout and fast growing companies is an interesting area but has been outside the delimitations of this study. Aspects connected to operational issues are left to be examined in future research.

This thesis provides an example of a developed theoretical framework applied to a real life scenario. Many of the reviewed frameworks in today's research are used on a theoretically ideal warehouse of rectangular shape in an undefined size. This makes them partly inapplicable to real life cases where redesigns are considered. More case studies with the usability of the frameworks in focus could therefore help practitioners within operations. Handfield and Melnyk (1998) state that it is of key concern that the practicality of the research is in focus since it is practitioners that is the target consumer of the research. To some extent this is not accomplished by today's research on warehouse layout design. By refining the layout design framework through multiple case studies it could be applicable to different industries. The framework might also be more valid and useful for practicing professionals within warehousing. The results of the framework has not been implemented in reality during the time frame of the project. For this reason the frameworks usability and ability to generate a physical solution has yet to be tested. This limits the results of the study and the practical trustworthiness of the framework.

To capture as many scenarios as possible some steps tend to be vague and relying on the users' experience within warehousing. Further research could therefore be directed to find models that focus specifically on the layout phase depending on preconditions. This could narrow the number of feasible layouts even faster and increase the efficiency of the framework. There are a number of theoretical frameworks describing the process on a higher level but within the presented steps there are gaps in guidance for practitioners. In this thesis the most time consuming steps has been the layout generation partly due to the complexity of finding adequate guidance in the generation process.

Further research

The focus of this thesis has been on fast growing companies which mean that the importance of the aspects and the applicability of the framework on companies in other parts of the company life cycle is unknown. Therefore there is a need to find the requirements and aspects of consideration for companies facing volatile demand cased from other phenomenon. Case studies on warehouses facing large variations in demand could therefore be interesting.

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Appendix

Appendix A – Pallet positions needed for Increase and Consolidation scenario

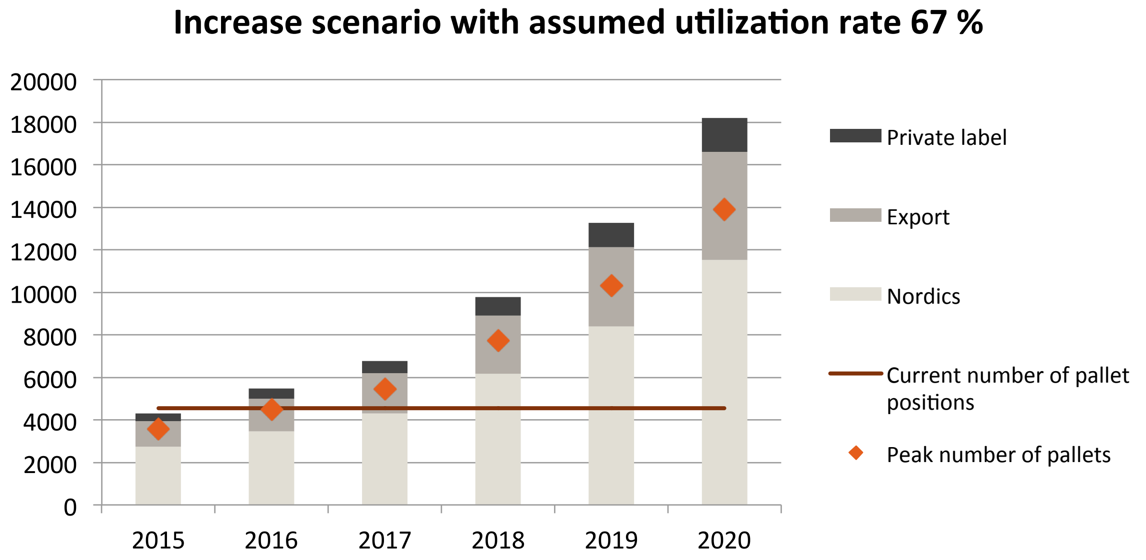

Figure A.1. Pallet position needed in increase scenario with utilization rate 67 %

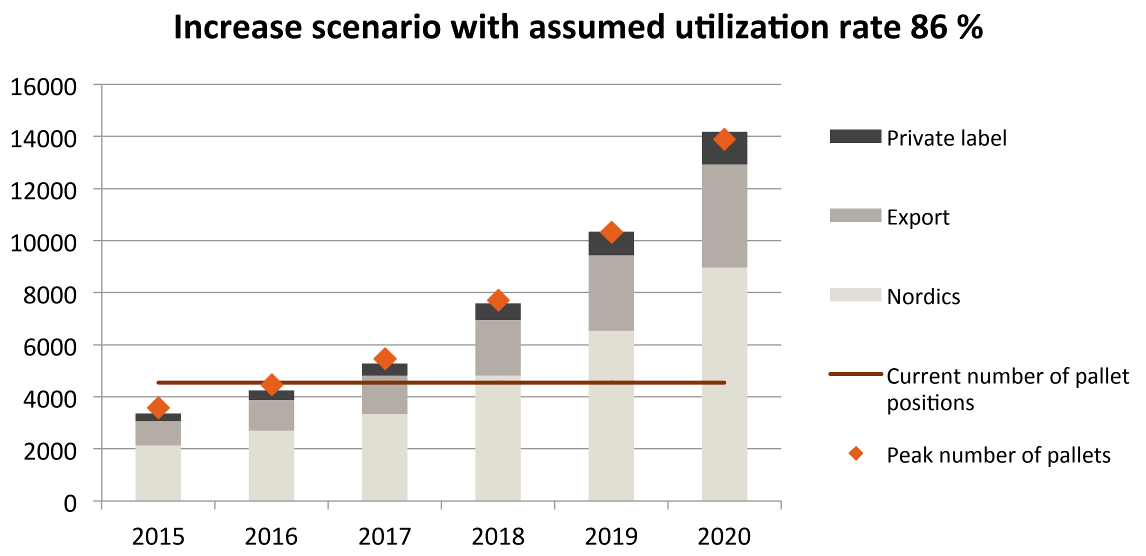

Figure A.2. Pallet position needed in increase scenario with utilization rate 86 %

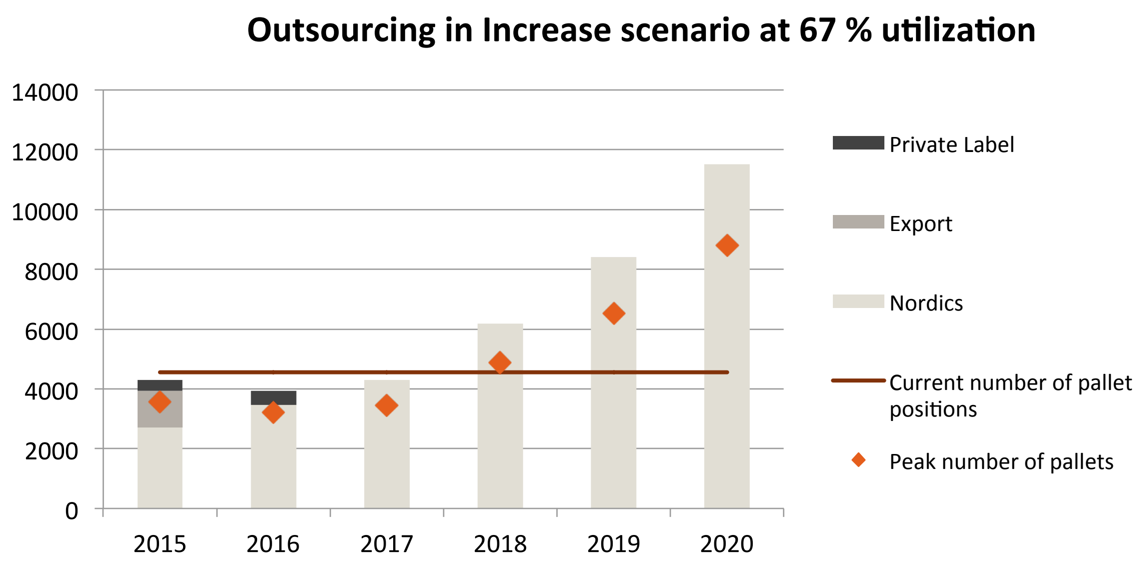

Figure A.3. Pallet position demand with outsourcing of export and private label goods in the increase scenario at 67 % utilization.

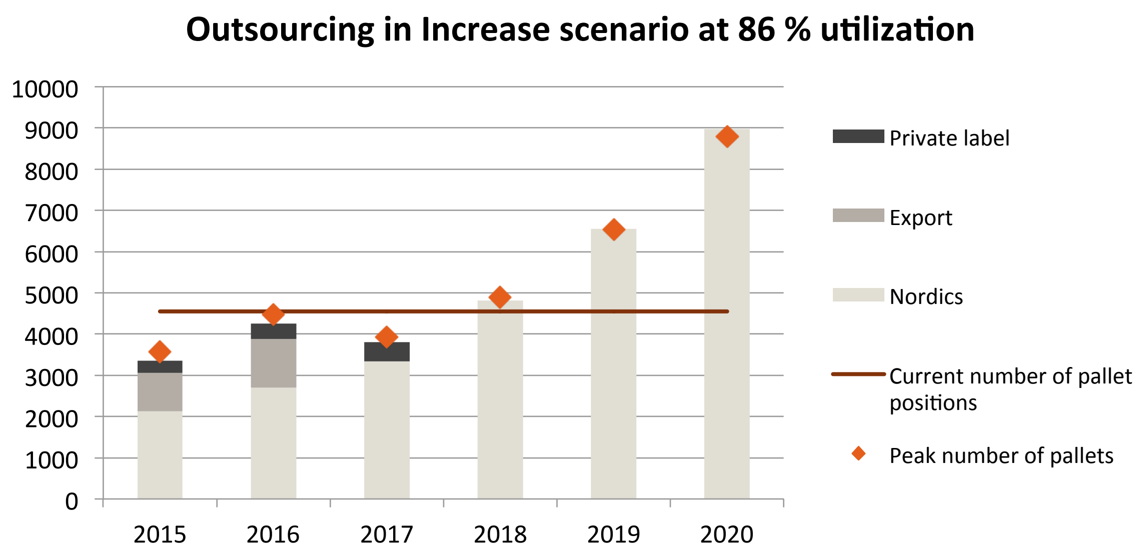

Figure A.4. Pallet position demand with outsourcing of export and private label goods in the increase scenario at 86 % utilization.

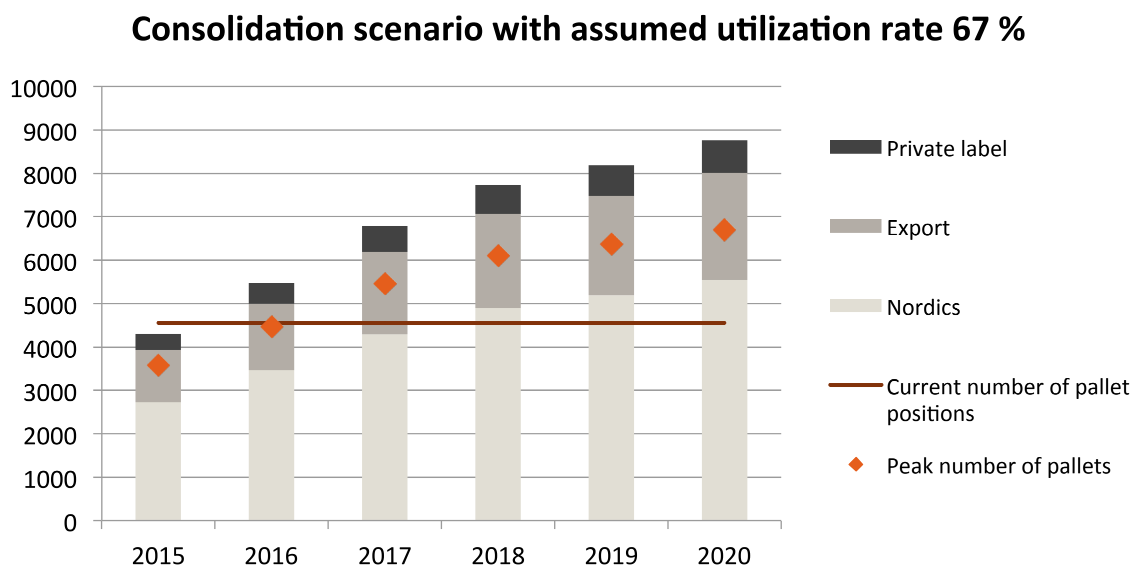

Figure A.5. Pallet positions needed in the Oatly warehouse in the consolidation scenario with an assumed utilization of 67 %.

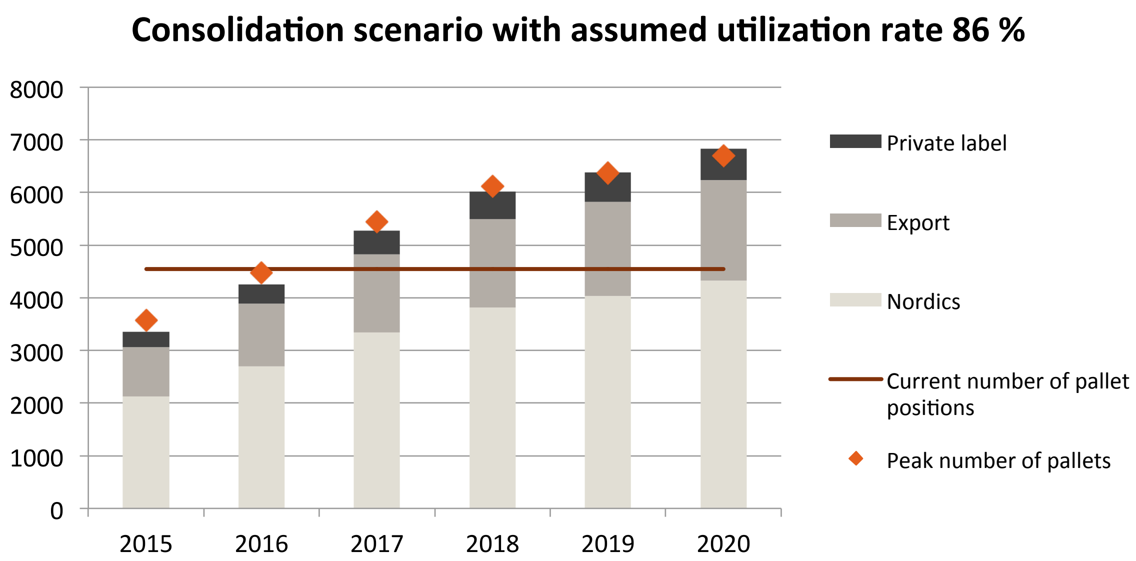

Figure A.6.Pallet positions needed in the Oatly warehouse in the consolidation scenario with an assumed utilization of 86 %.

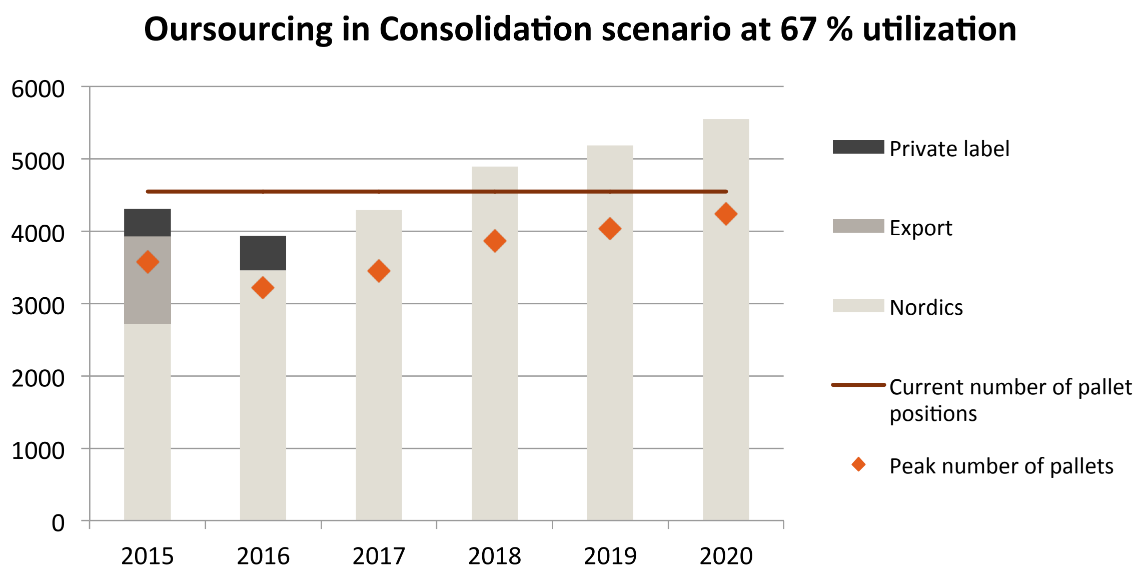

Figure A.7. Pallet position demand with outsourcing of export and private label goods in the consolidation scenario at 67 % utilization.

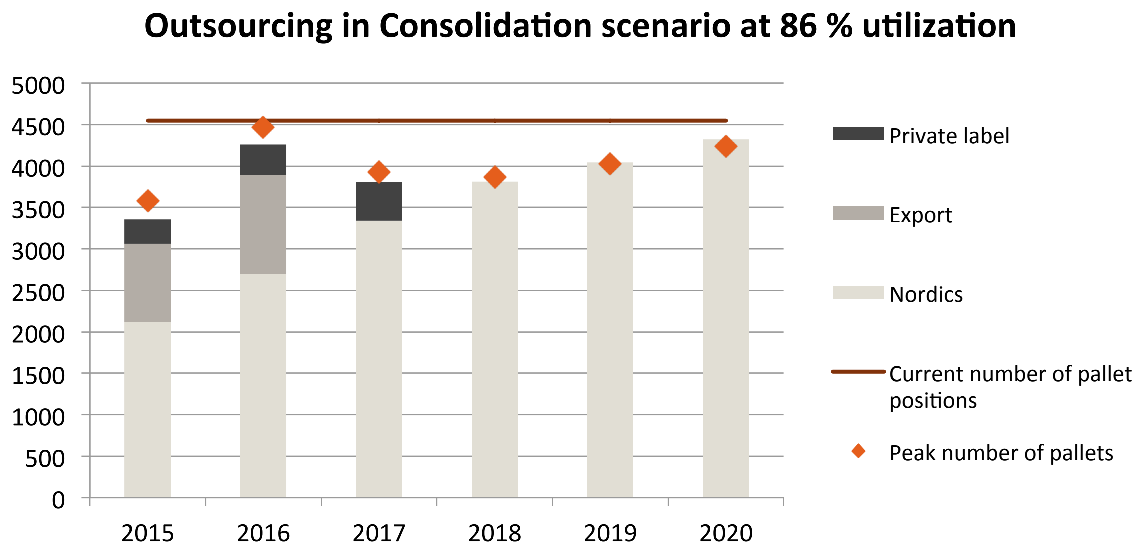

Figure A.8. Pallet position demand with outsourcing of export and private label goods in the consolidation scenario at 86 % utilization.

Appendix B - Layout suggestions

Layout suggestion for internal building

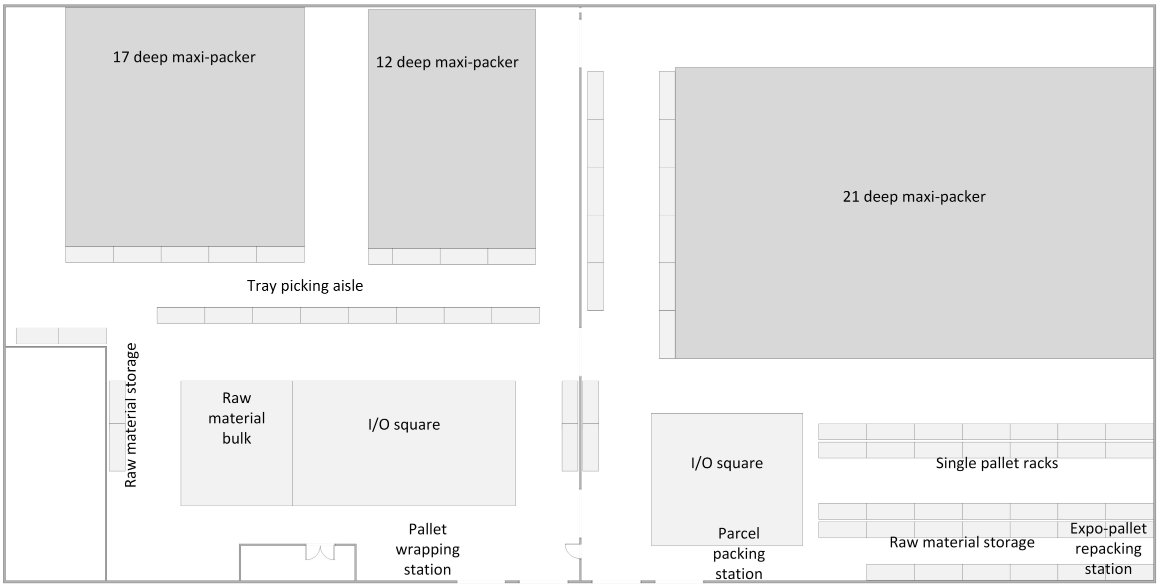

Figure B.1. Layout suggestion considering changing the 35-deep maxi-packer to two maxi-packers 12 and 17 pallet positions deep

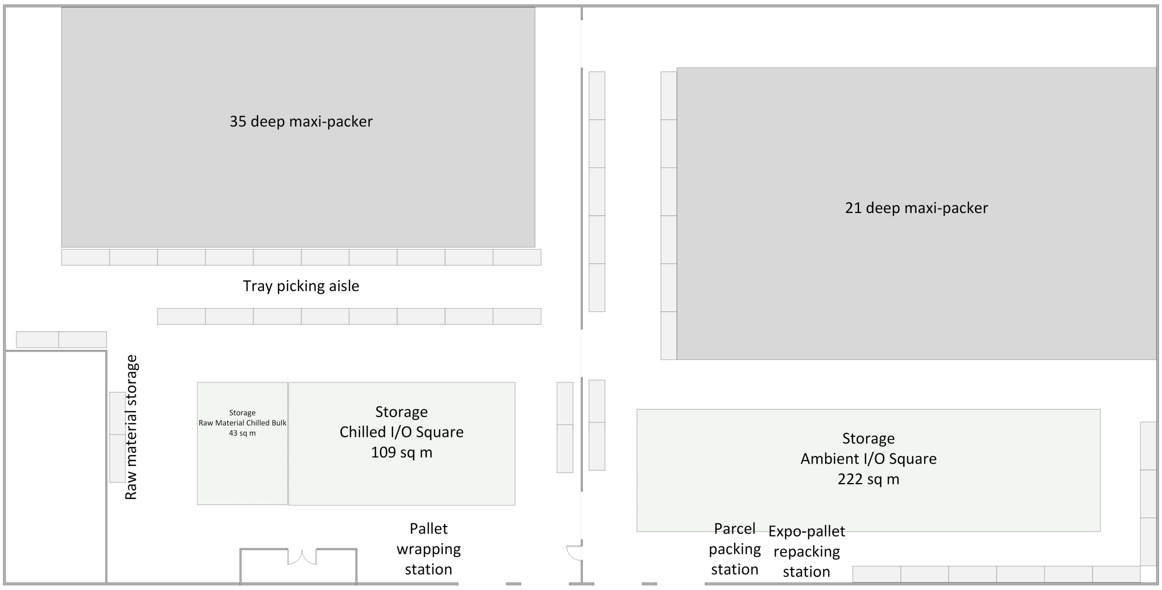

Figure B.2. Layout suggestion considering extending the squares by removing single-deep pallet racks and raw material storage in ambient section

Layout suggestion for 50 % expansion west

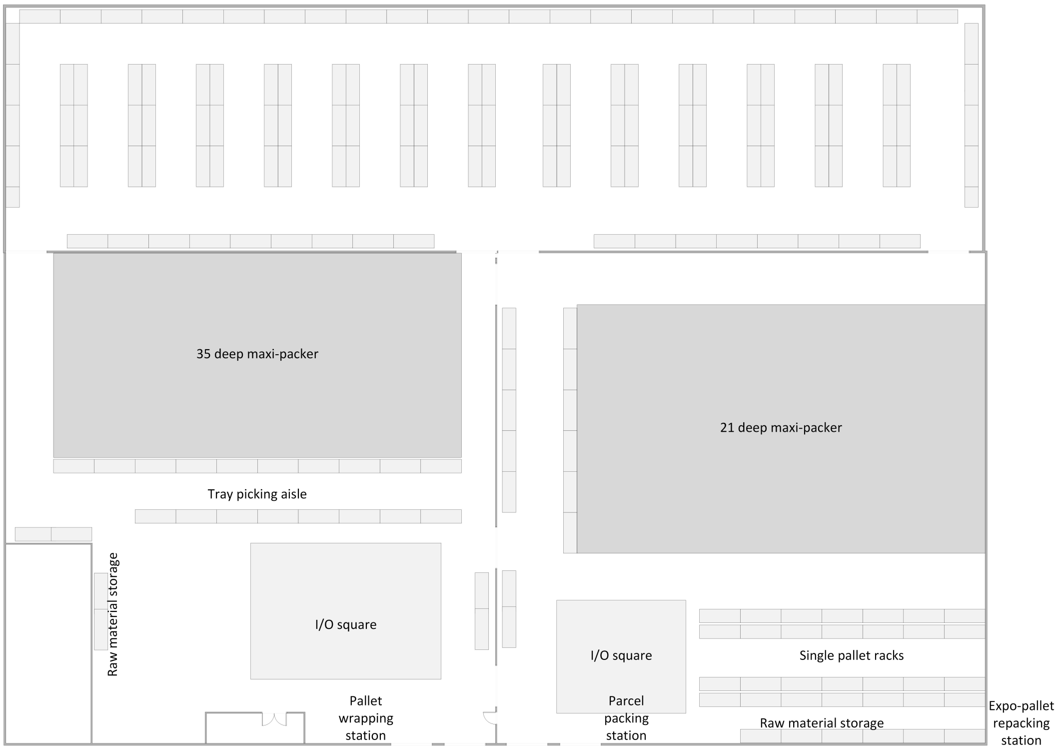

Figure B.3. Layout suggestion considering a 50 % expansion of the warehouse to the west which is filled with single-deep racks with standard 3 m aisles.

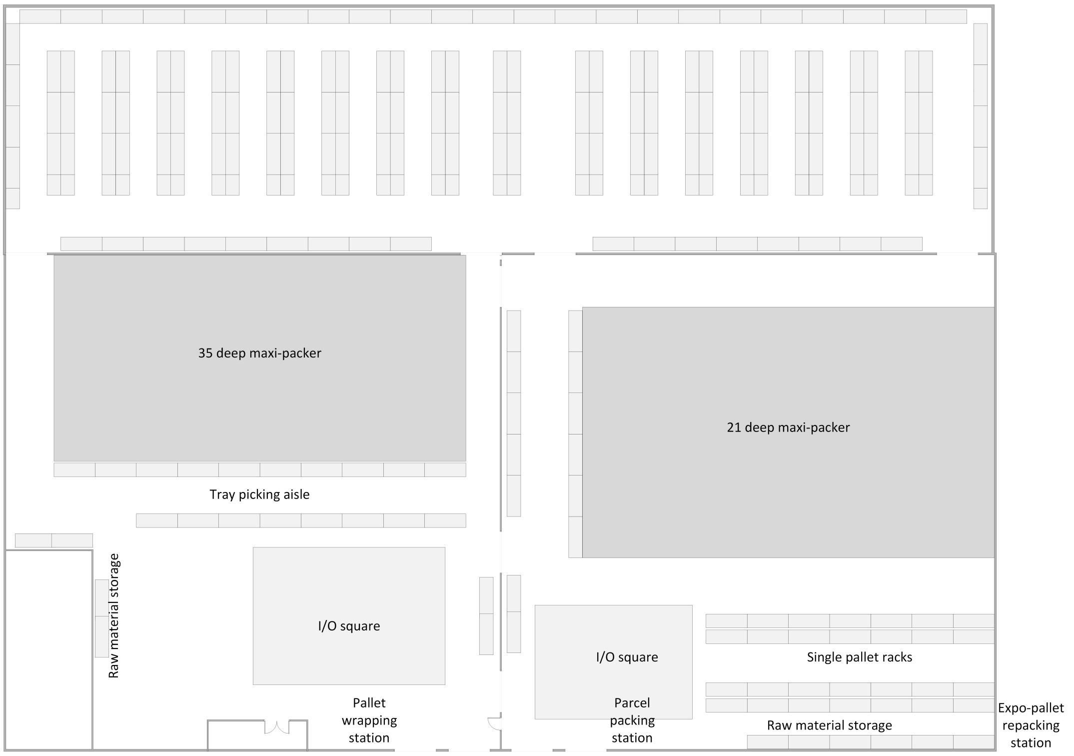

Figure B.4. Layout suggestion considering a 50 % expansion of the warehouse to the west which is filled with single-deep racks with a narrow 2 m aisle.

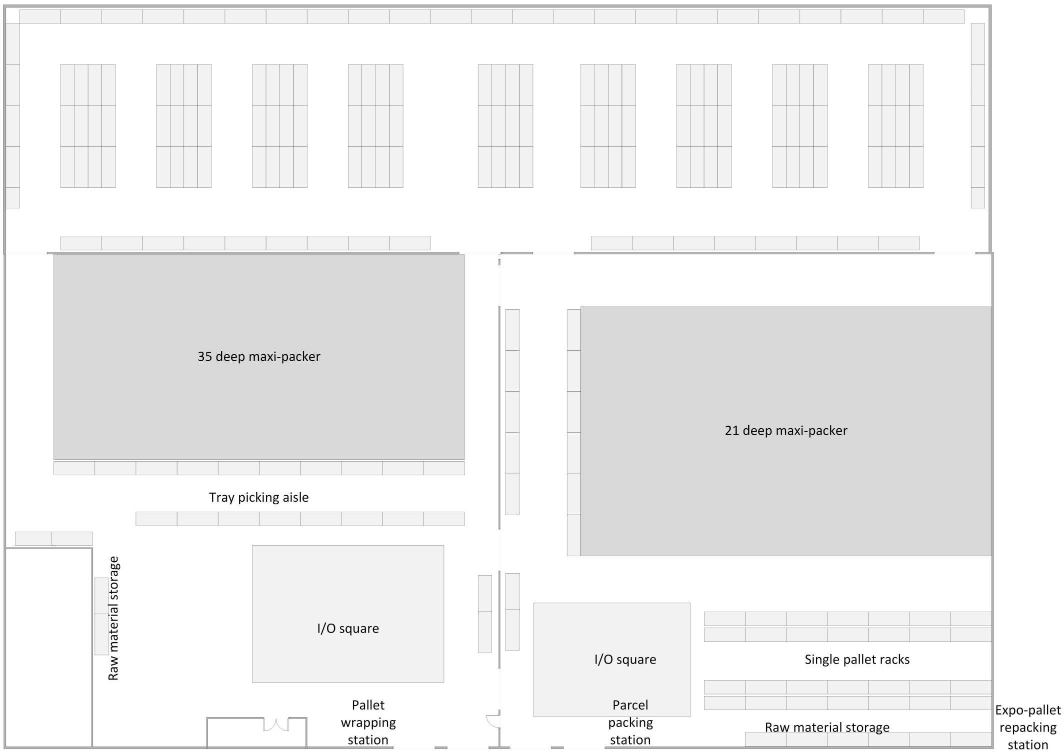

Figure B.5. Layout suggestion considering a 50 % expansion of the warehouse to the west which is filled with double-deep racks and single-deep rack along the walls.

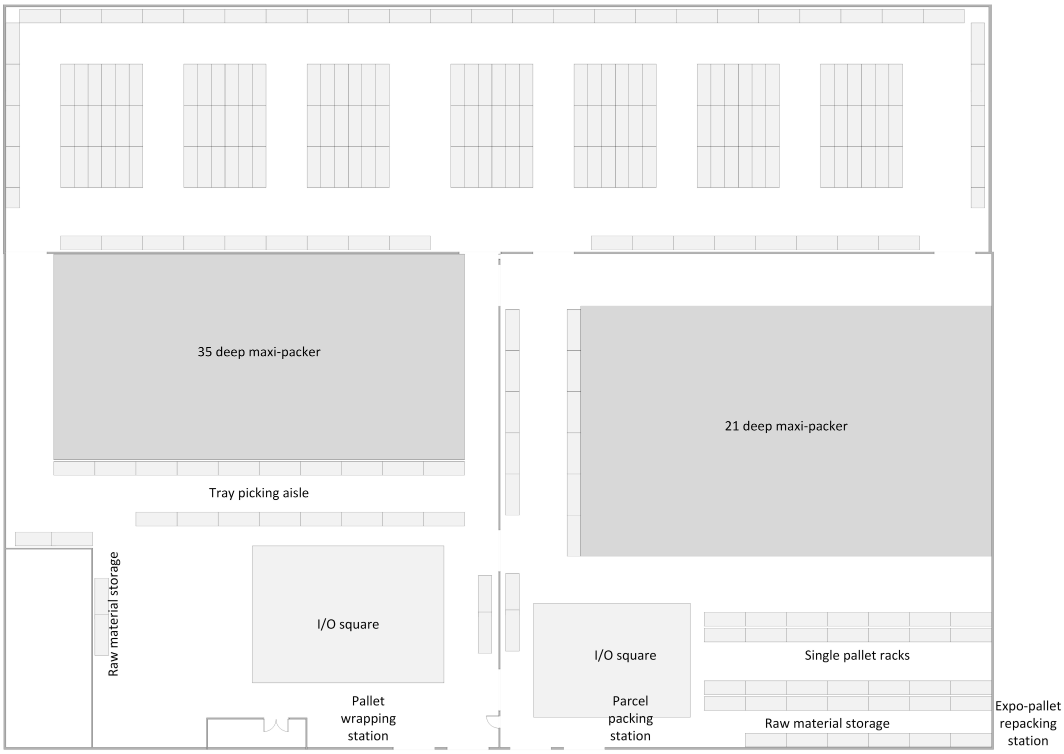

Figure B.6. Layout suggestion considering a 50 % expansion of the warehouse to the west which is filled with 6-deep roll racks and single-deep rack along the walls.

Further expansions

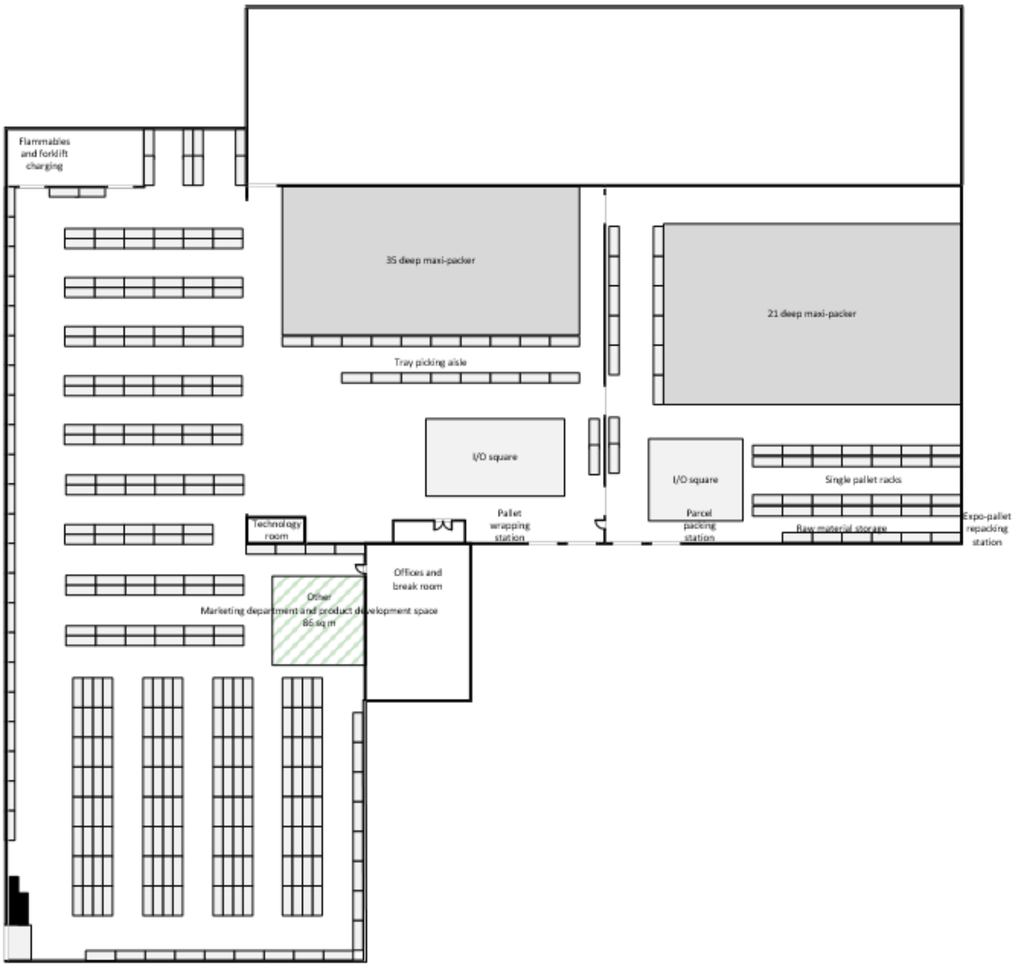

Figure B.7. Layout suggestion with an expansion south towards the production facility.

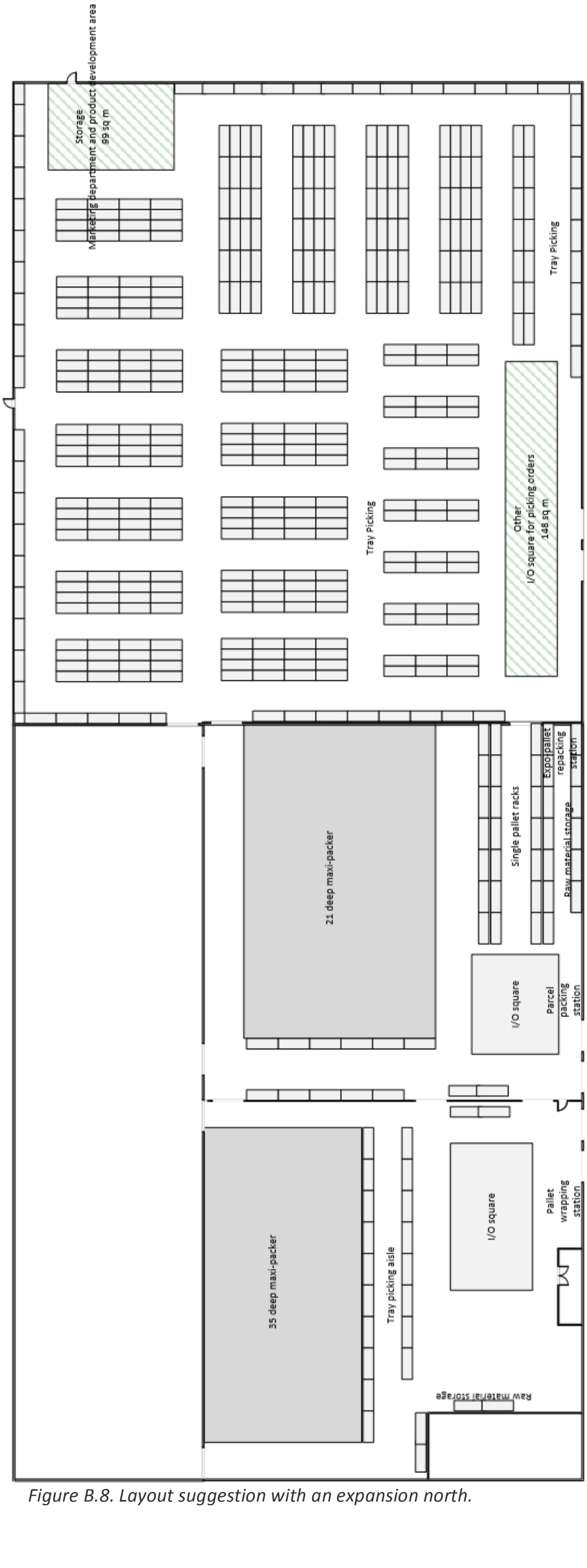

Figure B.8. Layout suggestion with an expansion north.

Generated Layout combinations to evaluate

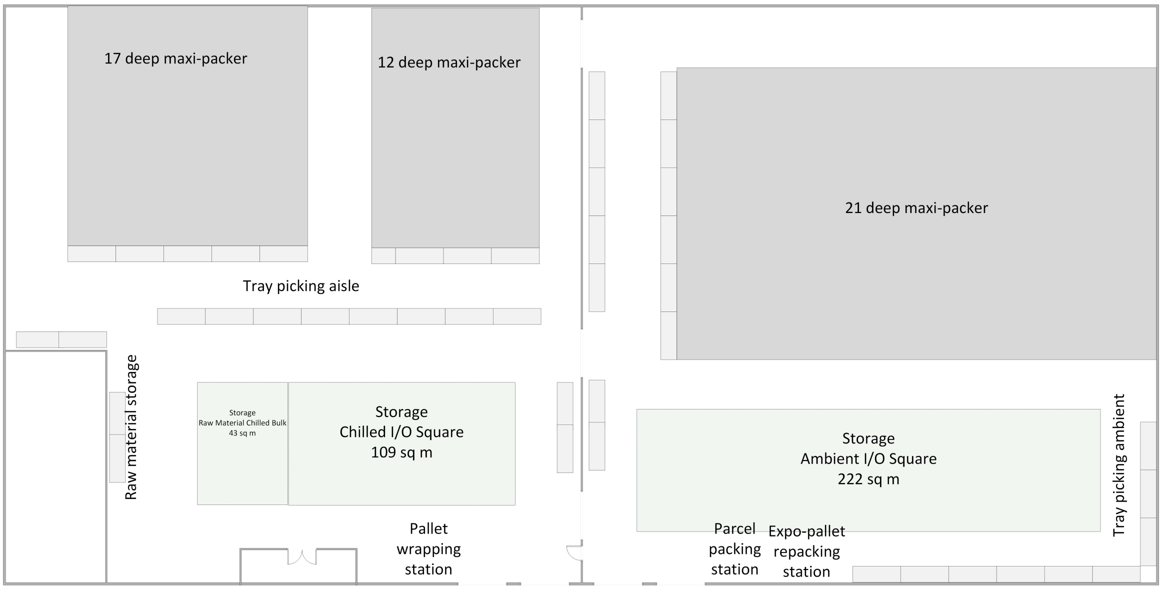

Figure B.9. Layout suggestion "Layout 1" combines the division of the 35-deep maxi-packer and the extension of the square.