Distribution Center design to match the capacity requirements of a fast-growing company

A case study at Mips

LUNDS UNIVERSITET

Lunds Tekniska Högskola

Authors

Ellen Jonasson	M.Sc., Mechanical Engineering	Lund University
Ludvig Olsson	M.Sc., Mechanical Engineering	Lund University

Supervisors

Ebba Eriksson	Ph.D., Candidate, Engineering Logistics	Lund University
Niklas Ingelund	Supply Chain Manager	Mips AB

Examiner

Joakim Kembro	Associate Professor, Engineering Logistics	Lund University

Mips

Department of Industrial Management and Logistics
Division of Engineering Logistics
Faculty of Engineering – LTH
Lund University

Acknowledgement

This master thesis is the final step toward our Master's degree in Mechanical Engineering, within Logistics and Supply Chain Management. It is not without assistance that this work has been successful, and it is only the right thing to do that we acknowledge the people that have been most involved during the process.

Niklas Ingelund, Supply Chain Manager, has been responsible for supervising the thesis on behalf of Mips. Thank you for your true enthusiasm and encouragement in delivering a useful and instructive project for the company and us. We experienced a close relationship and a genuinely inclusive welcoming to Mips, giving us the best possible experience at the company. As well, a big thank you to the other employees at Mips who have provided us and our project with your time and attention.

Ebba Eriksson, Ph.D., Candidate, has been supervising us and providing valuable feedback on conducting our master thesis on behalf of Lund University and the Department of Industrial Management and Logistics. Thank you for always leading us in the right direction and emphasizing concepts until they are understood. It has resulted in a sound and professionally written report.

Lund University and especially the Faculty of Engineering also deserve an appreciation for the knowledge and preparation that we have been given throughout our five years of studies — leading up to the culmination of our education, this thesis, and ultimately our future working life.

The last thank you is dedicated to each other. It has been a journey working together and a pleasure studying the concepts of warehousing and fast-growing companies. Alone the outcome of this thesis would not have been possible!

Stockholm, 6 of May 2022

Ellen Jonasson & *Ludvig Olsson*

Abstract

For every company that handles products, a purposefully chosen warehouse dictates their ability to create a smooth flow of products and ultimately their success as a company. This is true, not the least, for fast-growing companies. A purposely designed warehouse has the capacity to handle the demand of the product that it holds proficiently. A poorly configured warehouse can lead to congestion, reduced productivity and ultimately fail to deliver the products.

This thesis focuses on Distribution Center design to match the capacity requirements of a fast-growing company. This includes physical size to last for the coming two years, layout, equipment & automation- and information systems. The research is conducted in the case of Mips, an ingredient brand that creates a safety system used in helmets. To configure a warehouse that suits their current strong growth, a framework is developed. The framework is based on a theory of warehousing, Mips' experience, and the background of already existing frameworks for warehouse design. The framework is also adapted to the situation of a fast-growing company.

The implementation of the framework has resulted in a proposed solution. A set of scenarios that are based on the Mips' growth rate, the portion of externally or internally sourced products, and varying quantities of safety stock gives a range of the warehouse size for storage of SKUs. From that, one number was determined, $1486m^2$. Other areas in the warehouse should be 620 m^2 and areas for employees $500m^2$. For a company with characteristics of Mips, having a medium to a low amount of SKUs and a low throughput per time unit, manual labor will suffice, and automated solutions will not benefit the operations just yet. However, electric forklifts and scanners with a WMS should be implemented. Furthermore, picking boxes of LFLs from racks will be used instead of consolidation since it provides better floor utilization. The layout should be a U-shape, and it should be shared storage for LFLs and dedicated storage for generic components. Also, there should be class-based storage with FPA and reserve area for generic components.

The developed conceptual framework is a proposition for other researchers and practitioners to implement. Therefore, the steps are made as transparent as possible to make the findings of the thesis transferable. The result is therefore, both practical for Mips to use when looking for a new DC, but also theoretical.

Abbreviations

3PL: Third-Party Logistics

AS/RS: Automated Storage and Retrieval Systems

CO: Customer order

DC: Distribution Center

EPS/EPP: Expandable Polystyrene/Expandable Polypropylene

ERP: Enterprise Resource Planning

FIFO: First-In-First-Out

FPA: Forward Pick Area

I/O: Incoming/Outgoing

LFL: Low Friction Layer

LIFO: Last-In-First-Out

MCW: Mips China Warehouse

MIPS: Multi-directional the Impact Protection System

QC: Quality Control

RO: Research Objective

SKU: Stock Keeping Unit

WMS: Warehouse Management System

List of figures, tables, and equations

Table of content

1. Introduction

This chapter provides a background of the case company Mips, and the problem at hand. The research objectives, delimitations of the study, and structure are also presented to set the frame of the study.

1.1 Disclaimer

The numbers related to Mips' growth presented in this thesis are fictional and should not be interpreted as accurate in any way or another. They do not have any correlation to each other or reality. The numbers are used to present a case and highlight the characteristics of a fast-growing company, and used in the framework to arrive at a solution. Because of confidentiality, the answers to the interview questions aren't attached in appendix A and B, and imaginary numbers are used in the calculations in appendix C.

1.2 Background

It is an established phenomenon that warehouse design is a complex task due to all the interrelating areas. These include the operations within the warehouse and refer to the role of the warehouse in its supply chain context and how the corporate strategy plays a crucial part (Mantela et al., 2000). Roodbergen et al. (2014) explain that a warehouse typically operates on a day-to-day basis. Thus a redesign that requires the shut down of departments in the warehouse is not an option for many companies. High costs from, for example, lost sales and shut down of operations can cost more than a warehouse investment itself. For this reason, it is essential for fast-growing companies or companies who, for some reason, are expecting considerable changes in demand to consider flexibility in their design process. This is to ensure a successful warehouse design aligned with the company strategy for the life span of the investment, with safety margin. Customer requirements and demand patterns in terms of seasonality are essential, whereas the latter is of utmost importance for a fast-growing company. For a company undergoing a strong growth process, designing its warehouses is harder to make because of the parameters' dynamic nature (Frazelle, 2002; Goetschalckx et al., 2010). A fast-growing company is defined differently among practitioners and researchers but as a means of standardizing the measurement, many scholars use the definition of Eurostat-OECD (2007, pg. 61): 'All enterprises with average annualized growth greater than 20% per annum, over three years should be considered as high-growth enterprises. Growth can be measured by the number of employees or by turnover. (...) A provisional size threshold has been suggested as at least 10 employees at the beginning of the growth period.' (Nicolare et al., 2015; Eurostat-OECD, 2007). Professionals agree that not planning for future growth is one of the biggest mistakes made when designing a new warehouse. Expansion and restructuring of a warehouse are very time-consuming and expensive activities. Thorough planning ahead to accommodate future growth makes expanding a smoother and more profitable business (Chu & Wright, 2022). Top tier consulting firms strongly agree upon this topic, concluding that '(...) companies must understand their strategy not only for today and tomorrow, but also well into the future—in terms of product portfolio, customer-order profiles, and other factors.' (Bustamante et al., 2020). In this thesis design is referring to; layout (aisle, lane depth, etc.), storage equipment (types of racks, etc.), handling equipment (types of forklifts, etc.), automation solutions (scanners, etc.) and information systems (WMS, ERP, etc.). Capacity is defined as the warehouse's physical size to match the requirements of size and labor, in this case, for a fast-growing company.

Warehouses have different setups based on their purpose. One is called Distribution Center (DC) and will be the main focus of this thesis. The common definition of a DC is 'a type of warehouse where the storage of goods is limited or non-existent.' As a result, DCs focuses on product movement and throughput (receiving, put-away, order picking, order assembly, and shipping) and information collection and reporting (throughput, utilization, and transportation documentation) rather than storage (Bookbinder & Higginson, 2005). In this thesis, both "DC" and "warehouse" will be used to describe the subject, as a DC is a type of warehouse, and theory regarding warehousing can be applied at DCs as well. Figure 1.1 shows a graphical representation of the flow through a DC.

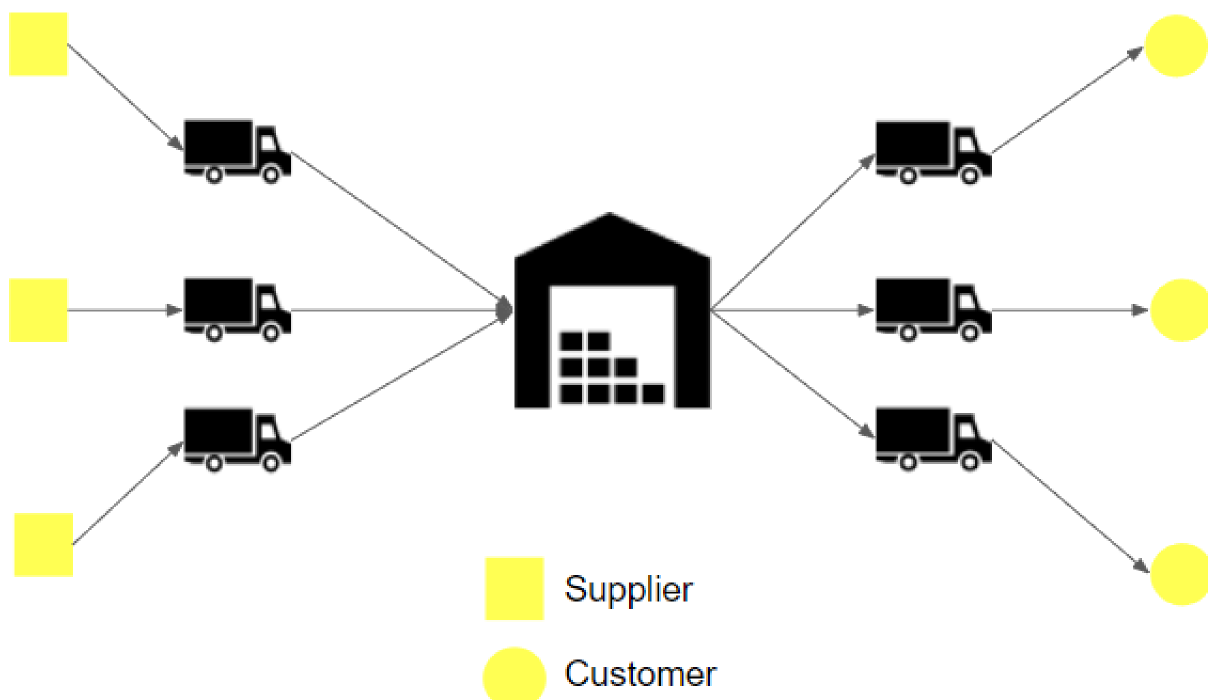


Figure 1.1: *DC flow chart.*

1.3 Company description

Multi-directional impact protection system (Mips) was founded in 2001 after years of development at Karolinska University Hospital and the Royal Institute of Technology in

Stockholm. The research started in 1996, launching its first product in 2007. Mips has its office in Stockholm and DC in Guangdong, China, hereafter called Mips China Warehouse (MCW). Mips is an ingredient brand. The product is a brain-protection system used in helmets, both for sports and construction work, protecting against rotational movement and impacts from all angles. The product is most often a plastic shell called Low Friction Layer (LFL). It exists in several variations and set-ups called "concepts," which can move inside the helmet and are custom made to each helmet model and size for the helmet manufacturers' products, see figure 1.2 (Isaksson, 2022).

Figure 1.2: *Mips LFL.*

Consequently, Mips does not sell products directly to end-users, and the helmet brands are the customers. 143 helmet manufacturers use Mips on more than 883 models in the low- to expensive helmet segment. Most of the revenue comes from sports helmets, especially from bicycle and snow segments. The company has had strong growth and is the leading company within the area and present on the Stockholm Stock Market with ~40% in operating revenue historically. Mips has, until 2021 sold 12,5 million units, and is currently having around 90 employees, including the team in Guangdong. The growth in the coming years is expected to continue, and Mips has only reached 10% of its potential market. The company has no production itself in comparison to a typical manufacturing company, and Mips can therefore ramp up its production by simply purchasing more from its suppliers. (Isaksson, 2022). Therefore, the company fulfills the research criteria of having strong growth, as well as a large possible market to look at and a scalable model to consider in the design.

1.4 Problem formulation & Purpose

As brought upon in the background, designing a DC for a fast-growing company is challenging and crucial in dictating the company's future success. For Mips, MCW must follow the company strategy with its most important performance measure of fulfilling all customer orders within expected time and correctness. Thus, the research aims to investigate and propose a *Distribution Center design to match the capacity requirements of a fast-growing company, in the case of*

Mips. The research is aimed to be useful for Mips specifically and applicable for other companies with similar contexts. The situation in which Mips finds themselves is that their current leasing agreement of their DC is due to end in the current year. Since they have grown with ~40% in operating revenue annually during the last four years, they now need to consider how to design the new DC to match the future capacity requirements. This is an important topic for them, which will dictate their ability to operate in the near future. Considering their uprising momentum, a badly functioning DC in terms of design and capacity could be harmful to their ability to deliver their product to the markets, harming their established reputation. Mips want to lease their new DC since it would be neither time-efficient nor economically justifiable to build or buy a new warehouse. Mips wants the new warehouse to last for two years, until October 2024, as it is difficult to plan for longer than that due to all changes in our surroundings, such as covid and deglobalization. The location of the DC will be in the same city as today. Mips care for their workers in the DC and do not want to force anyone to move to another location. The customers are also currently located close to Guangdong (Ingelund, 2022).

1.5 Research objectives

To aid the research in a steady direction and with a clear purpose related to the background and problem formulation, Research Objectives (ROs) are formulated (Indeed editorial team, 2021; Dudovskiy, 2022).

RO1: Formulate a new conceptual framework to match the capacity requirements of a fast-growing company.

RO2: Propose a DC design for Mips by implementing the developed conceptual framework.

A literature review becomes the frame of reference for DC design to match the capacity requirements of a fast-growing company, and looking into previous conceptual frameworks is a part of that. A new conceptual framework to match the requirements of a fast-growing company is then developed using information from Mips, the literature review, and the previous conceptual frameworks. The newly developed conceptual framework is then applied at Mips, and from that, a DC design can be proposed.

1.6 Delimitations

The output of this research, discussions, and conclusions are intended to be widely applicable. However, the limited timeframe of 20 weeks justifies narrowing the scope and establishing delimitations. No Third-Party Logistics (3PL) provider was considered since it is not relevant for Mips as they want to keep their employees. This is otherwise a solution many fast-growing companies use. Instead, the DC will be leased, which also means that the result will not be an exact design of every part of the new DC as it will not be possible in practice. Operational aspects like work process configuration and scheduling of staff are not considered. The thesis will neither aim to change any corporate or supply chain strategy. Similarly, the thesis focuses on not deeply covering areas such as implementing digital systems, scanners, Warehouse Management System (WMS), etc. Honeycombing and double handling will not be considered, but the design configuration decisions will indirectly affect this and hopefully lead to effective use of the DC. Mips has a corporate strategy with high sustainability goals. However, it will not be directly considered in this thesis but for Mips to work on in their everyday operations. The products stay in the DC for such a short time concerning shelf life that neither that nor characteristics connected to external physical factors, such as temperature, humidity, etc., are needed to consider.

1.7 Structure of thesis

The thesis structure is divided into chapters with a clear vision. Chapter 1 has covered the background of the thesis, the problem at hand, the ROs, and the delimitations. This provides a base for the following chapters.

Chapter 2 Methodology: The methodological choices made throughout the thesis are presented. The research method and research design are discussed and determined to fit the aim of the study. The background for the literature review is presented. The three data collection methods; interviews & half-time presentation, correspondence, and archival records are described. Choices made throughout the data analysis in chapter 4 are discussed to relate them to the methodology. Lastly, strategies for trustworthiness are covered to ensure the quality of this thesis.

Chapter 3 Frame of reference: Theoretical findings associated with the unit of analysis are presented. The literature consists of general warehousing and warehouse design and capacity. Warehousing, in general, is used to formulate a foundation of what warehousing is about. The warehouse design and capacity chapter then build on top of that with more specific concepts associated with warehouse design and capacity requirements for a fast-growing company. The last part is a literature review on conceptual frameworks for DC design, and is used as part of developing a new conceptual framework in chapter 4.

Chapter 4 Conceptual framework: This chapter is the link between the literature review of existing conceptual frameworks (chapter 3.3) and RO1, to formulate a new conceptual framework to match the capacity requirements of a fast-growing company. It is made by beginning with understanding the requirements of a fast-growing company, using theory and information from Mips. The next step is to apply that information to the previously developed frameworks for warehouse design in 3.3. It leads to a conceptual framework with six steps that later on are applied to Mips.

Chapter 5 Applying the conceptual framework at Mips: This is RO2 (*Propose a DC design for Mips by implementing the developed conceptual framework*). The new conceptual framework developed in chapter 4 therefore here applied at Mips. Each of the six steps in the frameworks is used, and a summary of the key takeaways from each step gets a conclusion. The information in this chapter is based on interviews with employees and correspondence when nothing else is stated.

Chapter 6 Conclusion: Here, the thesis is concluded by summarizing the key findings and answering the research objectives. Contributions to practice as well as theory are highlighted as well as suggestions for future research. The choices made throughout the journey, limitations of the study, the credibility of data, sources, and the persons interviewed are discussed. Thoughts regarding the new conceptual framework and the final recommendation are also presented.

2. Methodology

The methodological choices made throughout the thesis are presented. The research method and research design are discussed and determined to fit the aim of the study. The background for the literature review is presented. The three data collection methods; interviews & half-time presentation, correspondence, and archival records are described. Choices made throughout the data analysis in chapter 4 are discussed to relate them to the methodology. Lastly, strategies for trustworthiness are covered to ensure the quality of this thesis.

2.1 Research method

Research is the process of collecting, analyzing, and interpreting data to understand a phenomenon (Leedy & Ormrod, 2001). To choose a methodology that is appropriate for the research, the first step is to find the right theory. According to different sources, there are a variety of research methods. Yin (2014) suggests that there are five predominant methods of research, and he proposes three conditions for a researcher to dictate the appropriate one, table 2.1.

Table 2.1: *Methods of research (Yin, 2014).*

Method	Form of RO	Does it require control of behavioral events?	Contemporary events in focus?
Survey	Who, what, where, how many and how much	No	Yes
Case study	How and why	No	Yes
History	How and why	No	No
Experiment	How and why	Yes	Yes
Archival analysis	Who, what, where, how many, and how much	No	Yes and no

Looking at the ROs found in section 1.5, the appropriate method can be established. The ROs are a question of *how* and *why.* Even though the ROs in this thesis are not explicitly asking it, it is underlying in all ROs since they aim to provide in-depth knowledge about what factors contribute to a particular result. A case study provides a deep understanding of a problem and its factors since ROs typically address the reasons behind a result rather than the result itself. Furthermore, a case study does not care for control of behavioral events but does emphasize focus on contemporary events (Meredith, 1998; Yin, 2014). It is therefore highly suitable for conducting this research. For a case study, the phenomenon can be studied in its natural setting and include data from direct observation, systematic interviewing, and public and private archives (Leonard-Barton, 1990; Meredith, 1998). There must, however, be decided if it is a single-, multiple-, retrospective- or longitudinal- case study. In table 2.2 the alternatives are presented.

Table 2.2: *Types of case studies (Frohlich et al., 2002).*

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

The purpose of this thesis is to determine the design and capacity aspects for Mips new DC. It could therefore be viewed as a single case study since it studies a specific case and situation (Yin, 2014). The single case study allows the most profound analysis, which requires that the researchers have a complete understanding and access to relevant data for the study, as in this thesis (Frazelle, 2002). The fact that single case research only studies one case, means that the result is not necessarily applicable in other cases and leads to one of the limitations of this study (Eisenhardt, 1989). As the research aims to make it useful for other companies in similar contexts, it is of high importance to have this limitation in mind.

2.2 Research design

The research design is developed from the research method and is for a case study, an iterative process (Yin, 2014). The phenomenon is the concept being studied, while the case of the study is defined as the unit of analysis. Having a well-formulated unit of analysis is vital since it allows researchers to address the correct purpose, find answers to the ROs, and develop new theories about the subject (Yin, 2014). For this thesis, the phenomenon is DC design and capacity requirements for a fast-growing company. The unit of analysis is a single case study of the phenomenon applied at Mips. This motivates the selection of further literature, data collection, and data analysis methods. For a graphical representation, see figure 2.1.

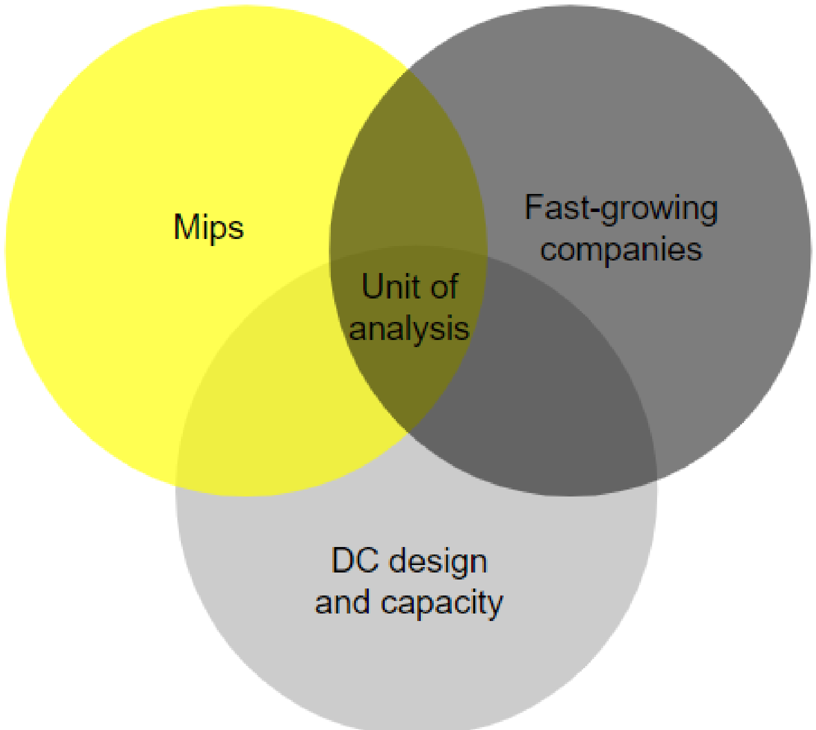


Figure 2.1: *Research design.*

Having a research design in place helps guide the process of defining & designing, data collecting, and data analysis to conclude and fulfill the purpose of the research (Yin 2014). The research process consists of these four areas and is iterative but can still be seen to follow the flow chart in figure 2.2. The steps in the research process that haven't been described yet will be elaborated on further in this thesis.

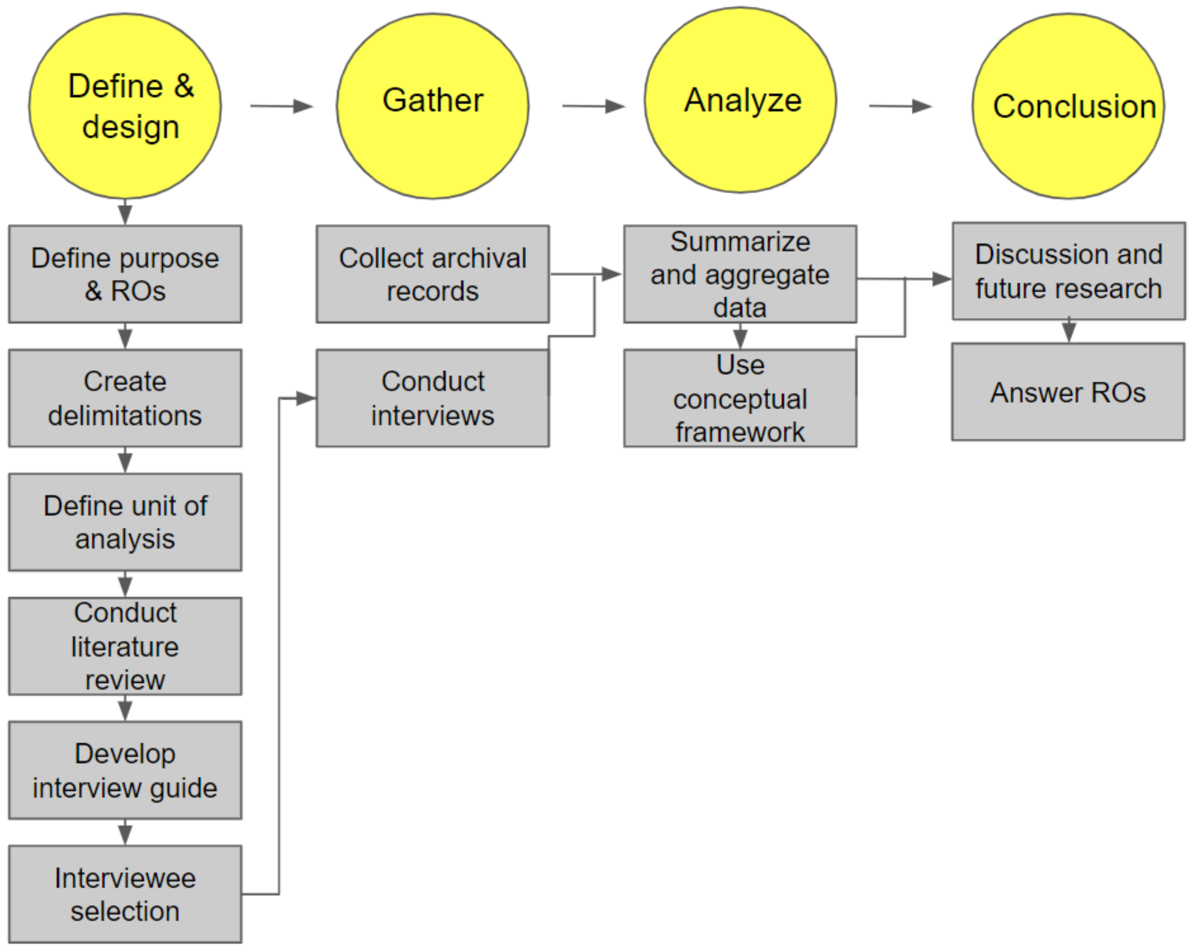


Figure 2.2: *Research process.*

2.3 Literature review

The frame of reference is the result of the literature review. Since it determines how the conceptual framework is built, it plays a key role in setting the quality of the conducted research. It builds an understanding of theoretical topics and terminology and suggests useful research methods (Rowley & Slack, 2004). The literature review is carried out by reviewing already published research about the subjects related to or relevant to this actual research. Setting the frame of reference can be mainly divided into two phases. Initially, the search is made broad to work out the range or spectrum of how previous research defines the realm of this subject. The next phase of the literature review is finding research regarding the concepts and areas uncovered during the first phase of the literature review. During this phase, the goal is to uncover the theory about certain concepts used for the analysis and forthcoming the research. The dividing line between the two phases and their targets is a strategy chosen with consideration to research regarding literature reviews (Höst et al., 2006). Frohlich et al. (2002) explain how the boundaries between a phenomenon and the context are not clearly defined or evident. Advantageously, researchers ideally want to investigate both as the chosen context is relevant to the phenomenon that the research aims to study. It is important not to set a specific context too easily to study the phenomenon but to iteratively discover the context of relevance to the phenomenon of interest. this constitutes a great part of the discoveries and insights. The methodology for finding the right search words is an iterative process where initially, search words are used that are believed to be strongly connected to the subject. When related or similar words are found, the results increase in relevance. The new results are then used, which generates new related areas and search words. The literature is generated from the search terms and generates new literature by its list of references. The process of search terms can be seen in figure 2.3, going downwards from each yellow circle.

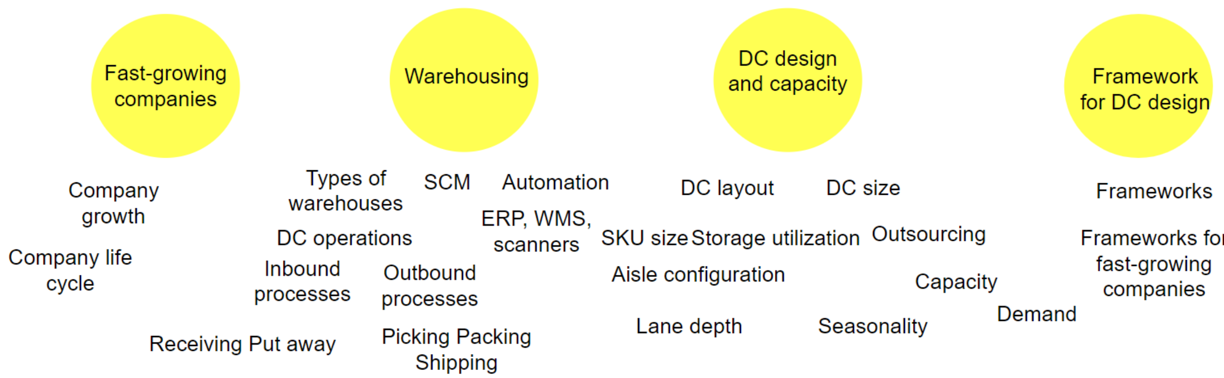


Figure 2.3: *Search terms.*

2.4 Data collection

Given the chosen method of case study, there are still various sources to collect data from. Qualitative data such as interviews are most commonly associated with case studies, which are often suitable for thoughts, strategies, and other intangible information. However, quantitative data such as archival records can also be necessary. It is measured in numbers, generally structured and statistically oriented (Eisenhardt, 1989; Holme & Solvang, 1997; Frohlich et al., 2002). Eisenhardt (1989) explains how even though quantitative- and qualitative data are distinctively different types, they are believed to have synergistic effects in research. This is explained by quantitative data being evidential in confirming or denying formulated hypotheses. Furthermore, quantitative data can find causal relationships in datasets that might be difficult to distinguish otherwise. Qualitative data adds to quantitative insights by being an explanatory variable that adds nuances and facilitates understanding of phenomena that can not or are hard to explain using only quantitative measurements. For example, interviews can provide information regarding how well the current situation is working regarding workload, safety, and other factors that are hard to tell from quantitative data. Even though data recovered from interviews are mostly qualitative and the data recovered from archival records are mostly quantitative, data is gathered across these boundaries. The relevant data sources providing the needed data collection points for the research are presented in table 2.3.

Table 2.3: *Sources of data.*

Source of data	Data type	Data collection points
Interviews	Qualitative / Quantitative	Warehouse and network concepts, product characteristics, material flow, process maps, departments, demand profile, ancillary activities, equipment, level of automation, etc.
Correspondence / spontaneous consulting	Qualitative / Quantitative	Projected future volumes, warehouse.
Archival records	Quantitative	Packaging data, sales data, historical inventory movements data, etc.

2.4.1 Interviews & half-time presentation

Frohlich et al. (2002) explain how interviews can be categorized into structured, semi-structured, and unstructured interviews. Structured interviews are found in surveys, for example, where the answers are predetermined. In semi-structured interviews, the interviewer has some planned questions depending on the interviewees' responses, and questions may be added or omitted. Unstructured interviews are fully informal. All questions depend on the evolving conversation between the interviewer and interviewee. The interviews performed in this thesis are semi-structured and aimed to guide the researchers in the development, and later use of, the conceptual framework. The interviewees are all employed at Mips to gain specific information as it is a single case study. During the interviews, notes were taken, and the answers were recorded. The questions were adapted to each interviewee. A half-time presentation was also held at the end of March to align the conducted work with Mips strategy. The interviewee, purpose, and when it was conducted are listed in table 2.4.

Table 2.4: *Interviews.*

Position	Purpose	Date
Head of Operations	Strategic information interview Half time presentation to align with Mips' strategy	14-02-22 29-03-22
Supply Chain Manager	Operational information interview Weekly reconciliation meetings Half time presentation to align with Mips' strategy	08-02-22 Every Wednesday 29-03-22
MCW Manager	Hands-on information interview Discussion of written summary from half time presentation	14-02-22 29-03-22
CEO Mips	Half time presentation to align with Mips' strategy	29-03-22

The interviews support the archival records. The current MCW and network concepts provide information regarding Mips supply chain to put it into perspective. The product characteristics support the quantitative data regarding grouping the products into categories. The material flow, process map, and departments support the theory regarding how the flow generally is in MCW and how the departments should be situated. The demand profile is a base for the quantitative data. Ancillary activities in MCW provide information that can't be found in the quantitative data but is important for the capacity of the MCW and the size of the departments. Today's equipment tells something about how the types of Stock Keeping Units (SKUs) are carried and where they are stored. The level of automation is collected together with information about how it is currently working and which potential additions could be suitable. This also provides better information regarding how the quantitative data is put into the system.

2.4.2 Correspondence

Throughout the process, weekly and sometimes daily conversations with the Supply chain manager and the MCW manager yielded information that was used in various parts of the analysis. For example, regarding projected future volumes and specific information about the current warehouse. The questions were asked as they emerged, and the type of information flow is not structured but rather spontaneous and on-demand based. New projections and altered figures appeared in real-time, and the analysis had to be sensitive to shifts and additions in information. For example, scenarios that were originally established to be analyzed were found to be non-relevant.

2.4.3 Archival records

Archival records mainly refer to quantitative data extracted in the form of computer files out of certain systems. Most often, this is an Enterprise Resource Planning (ERP) system deployed by the company covering, to varying degrees, the organization's functions (Yin, 2014). The collected data from Mips come from their ERP system and shared Excel files and have been used to understand the characteristics of the MCW in physical layout, SKUs, operations, etc. The data are extracted for 2017-2021. The extractions from the data collecting points are described in table 2.5.

Table 2.5: *Data collecting point and description.*

Data collecting point	Description
Packaging data	Information regarding each of the LFLs and generic components size, the amount in carton and pallet (for the majority of them). This is used to transform to the same unit of pallets.
Sales data	Provides information regarding the number of products sold for each year and is used to forecast coming demand.
Historical inventory movement data	Used to see how many of each component in stock during the years.

2.5 Data analysis

In case studies, it is essential to have a clear strategy for the analysis to avoid the risk of getting lost in the collected data (Yin, 2014). The process of condensing data to end up with patterns is described in the following three steps by Huberman & Miles (1994).

1. Summarize the data by creating a text to work on and trying out coding categories to find a set that fits.

2. Repackaging and aggregating the data by identifying themes and trends in the data overall.

3. Developing and testing propositions to construct an explanatory framework. Testing hypotheses, reducing the bulk of the data to analyze trends and delineating the deep structure.

These steps are used to analyze the answers from interviews and collected archival records. The frame of reference also gives directions on using the data. The answers from the three interviews are compared, and similarities and differences are found. When correspondence is held, no further analysis is made as the questions are specific, and no further understanding is needed. The majority of the data analysis was made in the quantitative data and archival records. It was used to decide the right size for the warehouse and included the compilation of Excel files and calculations within them. The first step was to reduce the bulk and unnecessary data. The extracted data must also be transformed from SKUs to pallets, which is done using data for packaging information. During the half-time presentation, it appeared that some SKUs are about to be phased out, and new ones were about to be added during the coming two years that the new warehouse is aimed to be used. Since there were no numbers for the packaging information of the new introductions, they had to be estimated. The seasonality traits were analyzed using historical sales data, and the average peak for all years was calculated. The pallet utilization was calculated from historical inventory movement data. The floor utilization was calculated from a picture of the current warehouse with measures, and the pallet utilization. The floor utilization is the percentage of the floor used for storage and not aisles, distance between pallets etc. The demand for LFLs is forecasted by Mips using their predictions of different categories' growth in the future. It is not strictly exponentially across the range of products, some increase and some decrease. However, the generic components are analyzed from sales data to see their current inventory and are forecasted based on growth from current figures. An ABC analysis is also made of generic components to design the layout concerning Forward Pick Area (FPA) and reserve areas.

2.6 Trustworthiness

Aastrup & Halldórsson (2003) tell the importance of assuring the quality of a research article. Especially when it is a single case study, it can not be validated through a large population. Instead, other criteria are needed to give the article trustworthiness and make the result applicable in other cases. Since the thesis will consist of quantitative and qualitative data, the following research quality criteria are used; credibility, transferability, dependability, and confirmability.

2.6.1 Credibility

Credibility is based on the idea that there does not exist a single objective reality. Instead, all respondents will have different perceptions of reality. The credibility is thereby measured by how well the researchers' attempt at representing the respondent's construction of their reality correlates with their perception. The methodological choices are; approved interview summaries, follow-up interviews, and validation interviews (Aastrup & Halldórsson, 2003).

The credibility of this thesis has been increased by having several types of data sources to create triangulation. Especially when it comes to interviews, where the interviewees had different competencies and stakeholders to understand the various aspects of the problem. Also, the fact that two supervisors with different positions have supported the work creates credibility by having close communication with them. As well as the possibility of performing follow-up interviews. The results in the thesis also steam from multiple sources. Quantitative results gained from the database, such as peak to average, are verified with employees from Mips. The credibility of the thesis increases because most of the numbers are quantified and then compared to people's views.

2.6.2 Transferability

Transferability reflects how it is possible to transfer the research findings into general statements or descriptions, defined as generalizability. However, no perfect generalization is possible, but rather that the degree of similarities in the sending and receiving context determine the level of transferability. Why it is important with rigorous descriptions of the contexts being studied. Generalizability can be increased both through the depth of observation and triangulation. The methodological choices are; multiple case study methodology, multiple populations (retailers and supporting actors), follow-up interviews, and rigorous case descriptions (Aastrup & Halldórsson, 2003; Meredith, 1998).

Regarding the nature of a single case study, the generalizability of this thesis is from the start less than that of a multiple case study. Instead, the transferability is made by thoroughly describing the context in which the research is conducted, for it to be useful in other contexts, and by conducting follow-up on interviews. Transparency with calculations and assumptions describes how insights are gained, and the process of attaining such conclusions can be transferred into other researchers' applicability. The rigorous description of the use of the new conceptual framework sets it in context with the aim of the study and can by that make it transferable and applicable for other to use.

2.6.3 Dependability

Dependability relates to the stability of data over time. It is determined through the replicability of research results and is also an important part of quantitative research. In qualitative data analysis, dependability is achieved through communicating the logic of method decisions and securing that one can follow the researchers' process towards the results. The methodological choices are; the methodology chapter, including the interview guide (Aastrup & Halldórsson, 2003).

The dependability of this thesis is increased by a rigorous interview guide and a detailed methodology chapter. The decisions made through the data collection and data analysis are also well stated. The methodology of finding existing frameworks for warehouse configuration in literature and then comparing them to each other to develop a new one creates a foundation for dependability. However, the calculations made to arrive at the suggested warehouse configuration are transparent and make it possible for future researchers to replicate for their research purposes. This is one aspect that increases the dependability of the thesis.

2.6.4 Confirmability

Aastrup & Halldórsson (2003) describe how confirmability aims to present results free of bias and prejudice. However, they argue that research methodology can never fully be separated from the researcher's thoughts and that objectivity is an illusion. They further describe that all data needs to be trackable so that conclusions back to their sources. The methodological choices are; semi-structured interviews, approved interview summaries, follow-up interviews, a methodology chapter including an interview guide, rigorous case descriptions, presented data analysis, and validation interviews.

This thesis uses confirmability by basing the analysis on data as much as possible and clearly state the made assumptions. Also, whenever anything in either the quantitative or the qualitative data has been unclear, questions about it have been asked to avoid making prejudiced conclusions. The data is also raw data and can be traced back to its origin. The past and the future data regarding pallets come from historical sales data. Historical inventory data have also been compared to sales data to confirm that the data is accurate, such as the peak to average value.

3. Frame of reference

Theoretical findings associated with the unit of analysis are presented. The literature consists of general warehousing and warehouse design and capacity. Warehousing, in general, is used to formulate a foundation of what warehousing is about. The warehouse design and capacity chapter then build on top of that with more specific concepts associated with warehouse design and capacity requirements for a fast-growing company. The last part is a literature review on conceptual frameworks for DC design, and is used as part of developing a new conceptual framework in chapter 4.

3.1 Warehousing

A warehouse is typically used to match the supply with the demand of customers. Usually, demand can change quickly while the supply changes more slowly. By using warehouses, companies can better meet the changes in demand. By supplying a safety stock of goods if the demand increases, or offering space to store goods if the demand decreases (Bartholdi & Hackman, 2014). A warehouse can also offer value-adding activities such as inspections, labeling, or module building (Bardi et al., 2011).

3.1.1 Types of warehouses

Warehouses are typically categorized into three variants. The industry distinguishes between production warehouses, DCs, and contract warehouses (Van den Berg & Zijm, 1999). Production warehouses handle raw materials, work in progress, and finished goods. DCs consolidate units from suppliers or break up grand loads in order for them to distribute into smaller quantities. Contract warehouses are those run by third-party actors (Mantela et al., 2000; Van den Berg & Zijm, 1999). Warehouses can play different roles at the same time in a supply chain. In small companies, it is common for production warehouses to fulfill external COs (customer orders) which means that the warehouses also function 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). A company can also agree with its suppliers or customers to store some of its goods at its warehouses. This can be seen as a 3PL solution, and costs need to be calculated for having a larger warehouse. As well, risks regarding for example vulnerability to the suppliers'/customers' negotiation position and longer lead times must be considered (Fei et al., 2009). As previously mentioned a DC is a type of warehouse and apart from consolidating units from suppliers, a DC will facilitate cost benefits with the transportation system by allowing full vehicle loads, holding inventory and decoupling demand requirements from production capabilities (Bernot et al., 2009). There are many different types of DCs, which can be seen in table 3.1. They are all designed to fit different needs and the activities performed in a DC depend on the type (Bardi et al. 2011).

Table 3.1: *Types of DCs.*

Type of DC	Description
Pickup and delivery	Serves local areas. Pickup and delivery activities to customers/suppliers daily.
Cross dock/consolidation	High-speed goods flow, goods are not stored. Consolidation of smaller orders or orders from different suppliers.
Break-bulk	Consolidation to or separation of large units before shipping to customers.
Relay	No goods handling, only change of driver.
Warehouse	Used to meet shifting demands by keeping safety stock.
Transfer	Freight shifts from one vehicle to another.

3.1.2 Warehouse operations

Warehouse operations in a DC take place through five processes: receiving, put-away, order picking, packing, and shipping. They can be divided into inbound processes (receiving and put-away) and outbound processes (picking, packing, and shipping). These are as well generally the departments of the warehouse and the allocation of the departments follows the logical flows (Bartholdi & Hackman, 2014; Kamoshida & Kazama, 2017). The operations can be seen in figure 3.1.

Receiving: The first activity that an arriving SKU encounters. Receiving includes getting an order receipt from the sender, quality control, inspection of goods, giving it a storage location, and labeling of the SKU. 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 a typical DC, the receiving process represents about 10% of the total operating cost (Bartholdi & Hackman, 2014).

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. Often full pallets are handled, which means that equipment to handle pallets is necessary and space in aisles to access storage locations. Put-away requires a fair amount of labor as products sometimes need to be moved to storage locations that can be located far away from the inbound area. The put-away process typically represents about 15% of total operating expenses in a warehouse (Bartholdi & Hackman, 2014).

Picking: Here, the SKUs are moved from the storage for CO. Picking is the activity around which many warehouses are designed (Gu et al., 2010). Order picking is conducted for different storage handling units such as pallet picks, carton picks, and piece picking. The different types of unit pick require different material handling equipment, routes, the configuration of racks, and warehouse design. The storage handling unit picked in combination with the equipment choice, determines the number of items picked in one route (Roodbergen et al., 2014). Order picking is the most labor-demanding process, representing about 55% of total operating costs. This is mainly due to the high portion of labor required when traveling to every storage location to collect each item belonging to a CO (Bartholdi et.al., 2019; De Koster et al., 2007; Aase & Petersen, 2004; Davarzani & Norrman, 2015).

Packing: The packing is to CO and can include a sorting element and a check for order completeness. The packing of the 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 involve packing products on pallets, into cartons, or a combination of the two. A warehouse being unit-load means that it handles only pallets. Depending on the packing process, different amounts of space are needed. Packing is, together with shipping, one of the activities with the least operating cost (Bartholdi & Hackman, 2014).

Shipping: The activity consists of allocating docks for arriving trucks or other vehicles used for transportation to customers, ensuring that the right goods are shipped, and registering the SKUs departure from the warehouse in an ERP system or similar to keep track of the inventory. Like the receiving activity, floor space is required for the shipping activity to ensure efficient material handling. Shipping is, together with packing, one of the activities with the least operating cost (Bartholdi & Hackman, 2014; Gu et al., 2010).

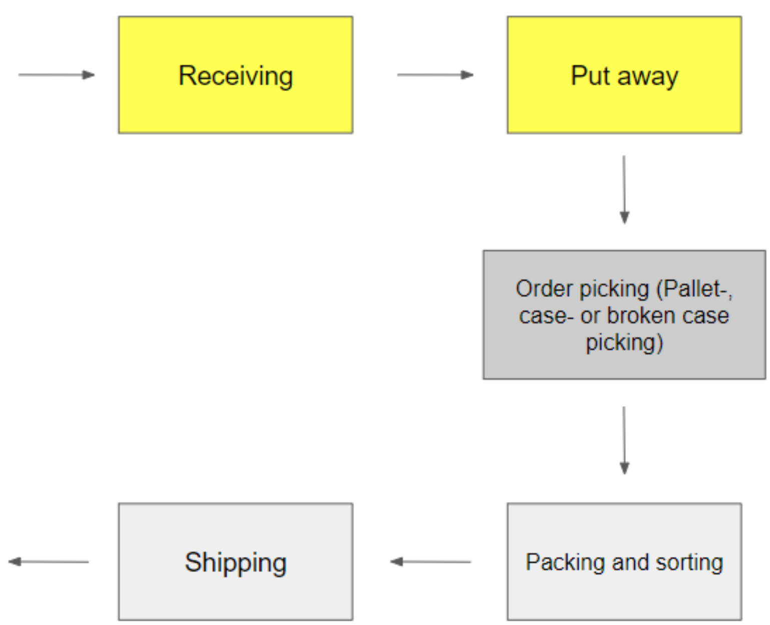


Figure 3.1: *Logical flow of departments and warehouse processes (Kamoshida & Kazama, 2017).*

Kembro & Norrman (2019a) discuss how several contextual factors influencing commerce businesses will impact the warehouse configuration. One of the configuration aspects is speed, characterized by short lead-time requirements, geographical dispersion, and differentiated goods. According to them, companies focusing on fast throughput should aim to create a warehouse design that enables fast flows and shortens internal lead times to the extent that is possible.

3.1.3 Supply chain strategy & warehouse design

De Koster et al. (2017) discuss how matching the demand for products to the supply across the layers in the supply chain is crucial for its success. Warehouses affect this outcome to a large extent and play a vital part in the setup. Generally, there are three aspects of consideration: location, design, and management of warehouses. Because of this, decision models are crucial for an organization's profitability. Thorough knowledge of these concepts will have a high impact on the efficiency level of operations, creating a good work environment for employees and facilitating high service levels. The design of a warehouse should emerge out of the overall strategic plan for it to be designed with intention. This means that the corporate strategy should dictate the warehouse design in order with the top-down approach (Bozer et al. 2010; Mantela et al. 2000). Beyond just matching the demand for an organization's products, a framework is used to determine the supply chain strategy based on categorizing the uncertainty level of demand and supply together (Lee, 2002). It is key to understand the demand and its characteristics to align the supply chain and warehouses with the strategy (Fisher, 1997). A supply chain with low supply uncertainty can be categorized as either efficient or responsive. This implies, for example, whether it produces to order or stock. For example, make-to-order supply chains generally keep a smaller safety stock and produce more complex products. In that instance, a suitable warehouse does not need to be very large but rather facilitates easier throughput (Jahnukainen & Lahti, 1999). See figure 3.2.

		Demand uncertainty	
		Low	High
Supply uncertainty	Low	Efficient supply chains	Responsive supply chains
	High	Risk-hedging supply chains	Agile supply chains

Figure 3.2: Supply chain strategy based on demand and supply (Lee, 2002).

3.2 Warehouse design & capacity

The many aspects of designing a warehouse, a large complex system, require experts and their analyses. To incorporate all inputs and solutions together, methods are needed. Many models optimize individual components of warehousing. Still, there is a lack of methodology that proficiently merges subproblems and their solutions in a complete setup and holistic view (McGinnis et al., 2017). Since the decisions in designing a warehouse are interconnected, the whole process is a matter of trade-offs and needs to be reiterated many times to avoid sub-optimizations (Goetschalckx et al., 2010; Mantela et al., 2000; Baker & Canessa, 2009). Different types of warehouses have various implications for the design of oneself and performance criteria of measurement commonly used. The storage handling unit implies a need for emphasis and decision-making regarding work process configuration, allocation of departments, and used equipment for handling (Bartholdi & Hackman, 2014). Demand patterns, seasonal changes, and expected growth rates are key in designing warehouses, not the least in a fastly growing organization. This is because those factors directly dictate the material flow and thus the needed design for the warehouse (Frazelle, 2002; Mantela et al., 2000; Goetschalckx et al., 2010). Also emphasized is flexibly in building the warehouse to be compatible with changes in storage or other handling requirements. This is called the warehouse, being a model of good housekeeping (Bozer et al., 2010).

3.2.2 Demand, forecasting & implications for capacity

The warehouse design is strongly dependent on the consideration of required space for every process in the warehouse. This space required for the processes results from an analysis that combines the current activity characteristics and the expected growth of the business. Spoken through several types of research is the importance of accommodating the capacity for growth when designing a warehouse (Mantela et al., 2000; Goetschalckx et al., 2010). A profound understanding of where in its life cycle a product exists will help deduct a greater perspective of how the demand will likely behave (Cox, 1967). The business life cycle covers two dimensions: the company's size and the time. Four phases divide the whole life cycle, start-up, growth, maturity, and decline. Figure 10 showcases the business life cycle. Knowing where the product exists is key in the decision-making process. For example, suppose a product is in its maturity stage. In that case, historical demand from within the same phase should give a better understanding than if historical demand was used for a decision while the product was in a growth phase. Likewise, if historical data were used while in the growth phase, in the belief that the demand would be constant, the warehouse would be under dimensioned (Carson et al., 2013). The theory makes sense of two different types of growth regarding activity in the warehouse, the demand may increase overall, or there may be an increase in the unique SKUs. See figure 3.3.

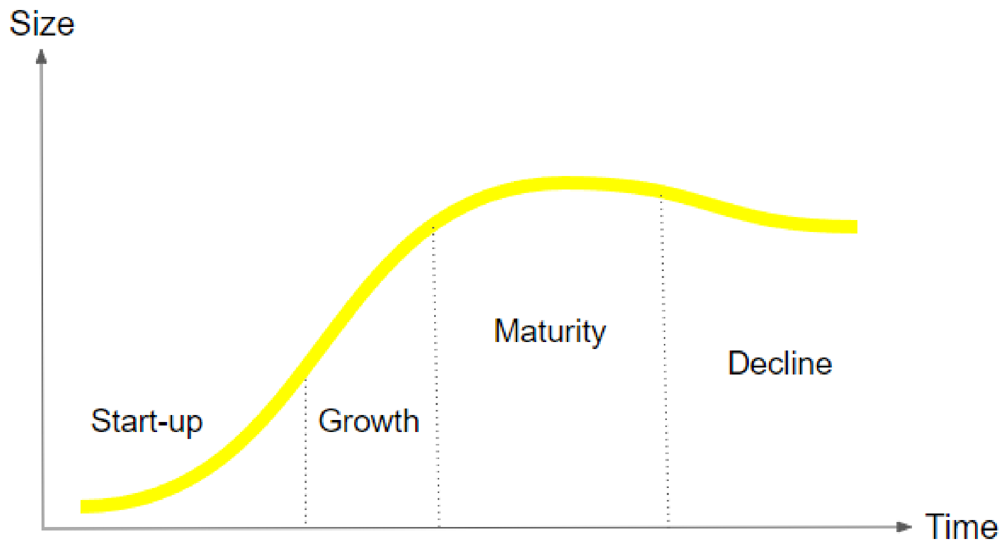


Figure 3.3: *The business life cycle (Theodore Levitt, 1965).*

Some businesses experience high seasonal variance. It can occur for several reasons and is defined by when the peak to average ratio is high, characterizing a large increase in demand over a short period. (Frazelle, 2002). The warehouse should be dimensioned for the peak, as it otherwise has to deal with overcapacity in its most hectic times. The utilization of floor storage should not be too low since it is expensive but not too high either as it might lead to overstock. (Payne, 2019; Opsdog, 2022). See example in figure 3.4.

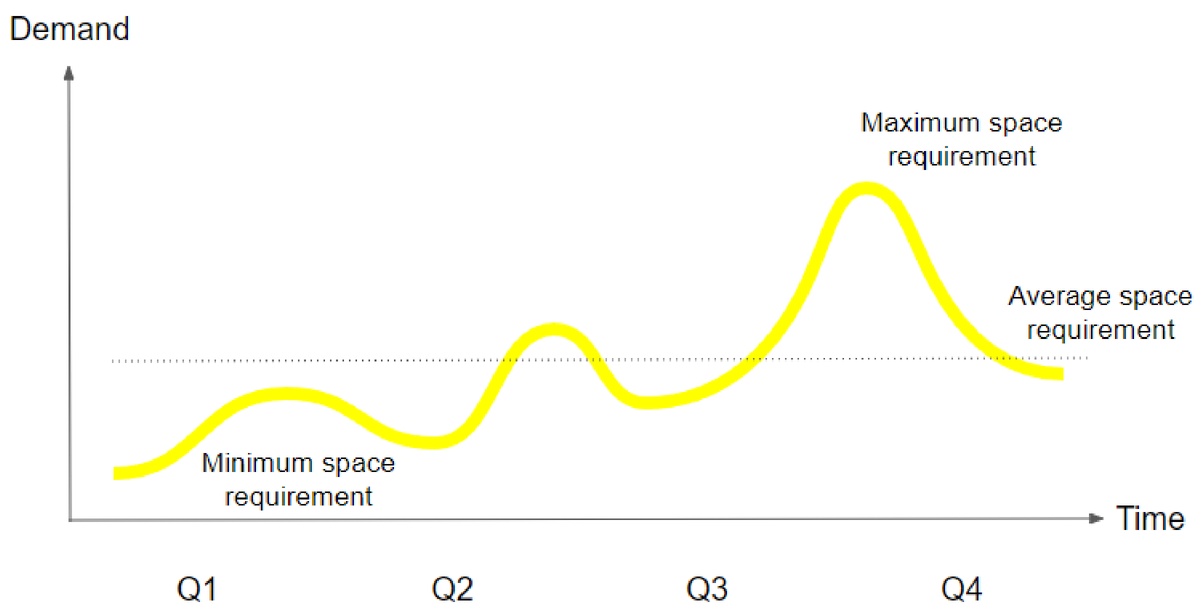


Figure 3.4: *Seasonal variance of demand. (Frazelle, 2002)*

Forecasting can be done using different methods. The methods used for forecasting are generally divided into three basic types: qualitative techniques, time series analysis/projection, and casual models. Qualitative methods use qualitative data such as experts' opinions or other parties' inputs and beliefs. This could be the personal or joint perception of a business's future sales expectations. Qualitative methods use human judgment and rating schemes to convert qualitative information into quantifiable measures. A qualitative method may or may not consider historical data. Qualitative methods include market research, visionary forecast, and historical analogy. Time series analysis or projection is entirely based on patterns and their changes. Forecasting methods of this nature are solely based on historical data. These statistical techniques are used when there is solid historical data and when relationships, as well as trends, are clear and stable. Fundamentally, these methods use a rate of change to predict the future. When these are known, different mathematical techniques create projections. A few examples of such methods are; moving average, exponential smoothing, and trend projections. Causal models are methods that model the business environment with refined and specific information on the interrelationships of system elements. They can consider special events. For example, a relationship is in what manner the demand is likely to increase due to a marketing campaign. Likewise to time series analysis or projection, historical data is used in causal modeling. Examples of causal models are the Regression model, econometric model, and Input-output model (Chambers et al., 1971). The differences between the techniques imply that the same technique is not useful at every stage of the life cycle. Time series analysis would be useless for a new product, whereas casual models of qualitative methods would be more relevant. At the same time, a well-established product and brand should gain the most accurate forecasting using time series analysis and projection. The suitability of a method is, therefore, in part, determined by what stage of the life cycle a product exists at. Other reasons may be the detailed level of data. Time series analysis or projection will need solid historical data to be accurate. Even though they should be more precise than qualitative measures, it may be worse in such a case (Chambers et al., 1971). Forecasting includes for example high and low demand items, variations in demand such as seasonal items or general peaks and lows. The demand of the product needs to be translated into a volume of orders for the warehouse to handle (Hassan, 2002).

3.2.3 The operations needs of space requirement & storage policies

The operations brought upon section 3.1.2 have individual requirements in terms of space allocation in a warehouse. The in- and outbound processes, receiving and shipping, need sufficient space to have room for the handling of products when loaded or unloaded from trucks, for example. Furthermore, they need room for packing or sorting the orders in connection with this. Both the docks from in- and outbound will result from the number of shipments handled and the turnaround time or set time in between shipments (Frazelle, 2002). The picking- and put-away processes need enough space through the aisles so that traffic with forklifts and other equipment can maneuver. Thus, this is dependent on the type of SKUs handled within the warehouse since this dictates what handling equipment is used. However, the most space requiring process is the storage of products. The products spend most of their time in the warehouse just being stored in the wait for later processes. To store, organizations can choose the use of either a dedicated or shared storage allocation policy. As their names suggest, dedicated storage allocation means that a certain location in the warehouse is only for a specific product to be stored at. Instead, using a shared policy means that the products can freely be placed wherever they should be decided. Dedicated storage means less administrative work, and the employees learn in time where the SKUs are located. Shared allocation is more flexible but needs more administration and can cause more faults in operation (Mantela et al., 2000; Bozer et al., 2010). The research on shared and dedicated policies suggests that shared policies can reduce travel time. One part of this reason is that less storage space is needed when SKUs have different inventory levels concerning their highest level. The space requirement for a dedicated storage allocation is determined so that the maximum number of SKU units can be stored for the total of all inventory (Bozer et al., 2010).

Companies often implement class-based storage together with shared/dedicated storage. This means that a SKU is dedicated to an area of a certain class, but it may be placed with shared/dedicated storage within it. Further, the items can be classified into A, B, and C categories, with class A as 70% av total volume, class B as 20% of total volume, and class C as 10% of total volume (Cormier & Gunn, 1992). It is also common for warehouse to be divided into a reserve storage area and a FPA. The reserve storage area has a random storage policy, while the FPA has dedicated storage. The reserve storage area contains bulk storage and can either be picked directly from with bulk products or be used to fill up the FPA. The FPA should contain SKUs that are picked often, and as the name says, it is aimed to be situated and configured, so it is easy to pick from preferably close to the shipping dock (Adil et al., 2020). It is common to store the SKUs in the FPA in racks. The supply should be approximately one month, and restock estimated as can be seen in equation 1:

$$(1)\ Number\ of\ restocks\ in\ the\ FPA\ = \sum \frac{Annual\ pallet\ flow\ of\ SKUs\ in\ the\ FPA}{Number\ of\ positions\ in\ the\ FPA}$$

The FPA must store enough to handle even large orders, however, very large orders should be picked directly from the reserve area. The number of SKUs assigned to the FPA depends on several factors. The number of storage positions in the FPA provides an upper limit, but to balance the workload between zones in this area, SKUs should be significantly less than the number of storage locations. Class A SKUs are placed in the FPA along with selected class B SKUs. Figure 3.5 shows the layout (Adil et al., 2020; Bartholdi. & Hackman, 2008; Kong & Masel, 2008).

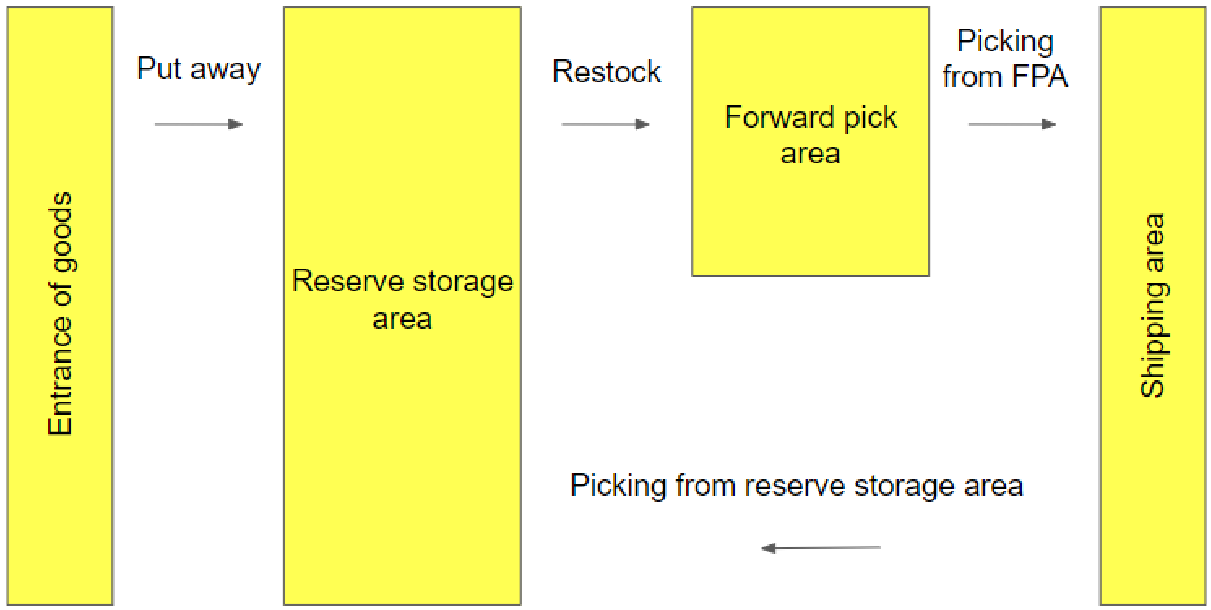


Figure 3.5: *FPA process.*

3.2.4 Aisle configuration, lane depth, & inventory policies

Bartholdi & Hackman (2014) describe how the storage locations of the warehouse can be more or less convenient depending on how the material flows in relation to it. A big part of this is ultimately where the goods arrive and where it leaves since this dictates the direction of material flow. In the simplest form, the convenience of a certain pick location is directly related to the total distance that it requires to be picked from, the less, the better (Bartholdi & Hackman, 2014). As the material flow results from incoming and outgoing positions, the docks need to be thoughtfully placed. In general, two distinct choices are possible. Either a flow-through layout, which means receiving and shipping docks are put on opposite sides of the facility. Or a U-flow configuration, where the products arrive and depart from the same spot in the warehouse. For a flow-through layout, there are many convenient spots. Locations from the same aisle are equally convenient. Whereas in a U-flow layout, the convenient spots are most closely placed to the point of receiving and shipping goods (Bartholdi & Hackman, 2014). See Figures 3.6 and 3.7.

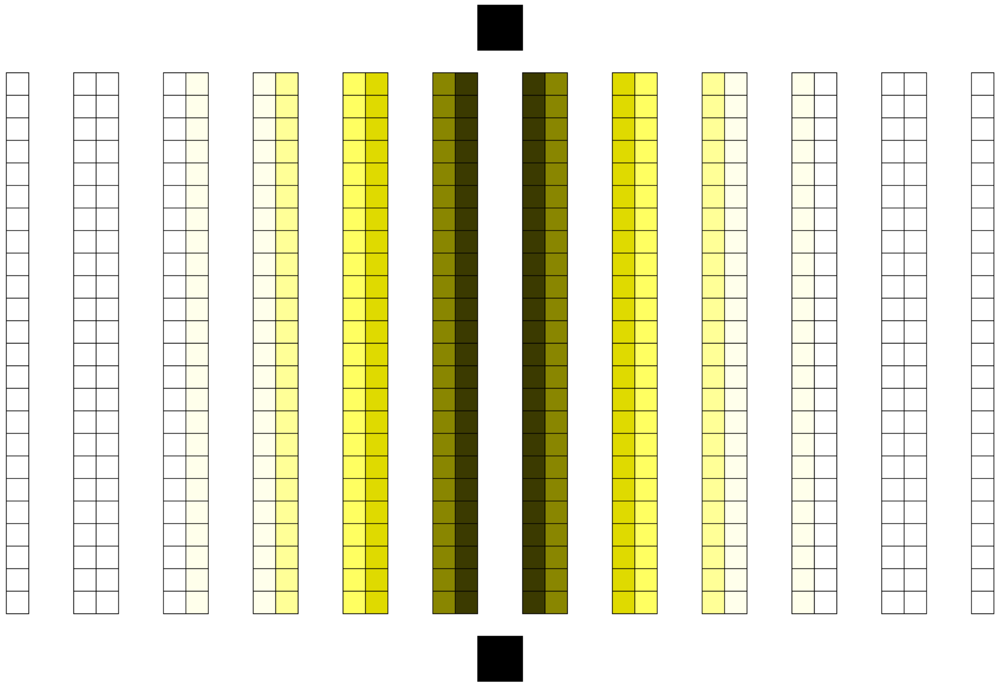


Figure 3.6: *Flow-through layout.*

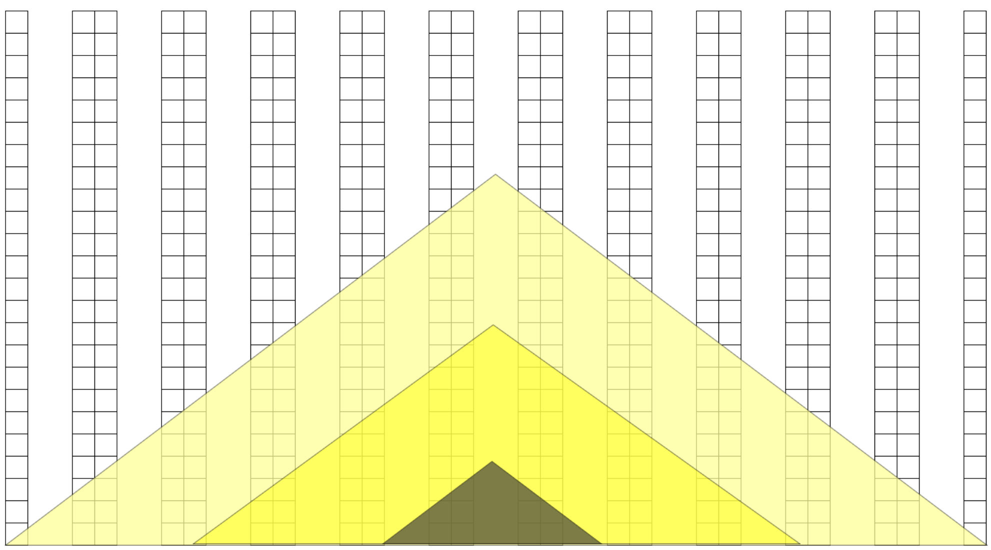


Figure 3.7: *U-flow layout.*

According to Bartholdi & Hackman (2014), this means that the setups have different implications for storage efficiency. The flow-through layout is suitable for high material flows because forklift traffic is less conflicting, and the docks can be purposefully specialized. The U-flow layout is adequate when the activity in the warehouse is the act of a small number of SKUs. The traffic will be more conflicting, but this is an opportunity for increased equipment utilization. Both in the means of using dual commands and the sharing of docks. If the pressure in receiving and shipping varies, then docks can be used for both operations interchangeably. The U-flow layout can more easily be extended horizontally and vertically, whereas the flow-through can only extend horizontally without the need to reconfigure docks. This has implications for the overall flexibility of the warehouse. In summary, warehouse aisle configuration can be viewed as a trade-off between efficiency in material handling and possible storage density. The most convenient layout for material handling will not be the densest storing configuration and vice versa. More specifically, having aisles rather narrow increases the cube utilization since a larger volume is stored when there are more racks. Consequently, tightly built aisles will negatively affect the ability to move and pick between them. Furthermore, broken aisles help navigate and find shorter routes at the cost of lost storage potential (Hassan, 2002). The products can be stored using different inventory policies. Many companies use the inventory model First In First Out (FIFO), meaning that the products that have been in the warehouse the longest time should be the first to leave. This is highly important for products with a shelf life to not to have obsolete products. Companies can, however, also use Last In First Out (LIFO), meaning that you pick the product that has entered the warehouse most recently, and the refill is made on top of items currently in stock. This model is only suitable for products without shelf life (Agarwal et al., 2020; Ramdasi & Shinde, 2021; Gu et al., 2010).

3.2.5 Order picking & storage handling units

A picking strategy can combine multiple considerations, and one warehouse does not have to use only one (De Koster et al., 2007). One choice of picking is whether to use parallel or sequence order picking. Parallel order picking is when multiple workers together pick the same order whereas sequence order is when an order is single-handedly picked by one worker. Orders can also be either batch-picked or picked alone (De Koster et al., 2007; Gu et al., 2007). Decisions on configuration and control of the picking process in the warehouse can be categorized as either tactical or operational. Koster et al. (2007) present the most common decisions associated with these levels, presented in table 3.2.

Table 3.2: *Warehouse decisions in relation to strategy.*

Area of decision	Level of decision
Layout configuration and the dimension of storage system	Tactical
Assigning products to storage locations	Tactical & Operational
Batch picking/grouping aisles into zones	Tactical & Operational
Order picking routing	Operational
Sorting and grouping picks of the order	Operational

Decisions of operation level have more impact on bigger warehouses with grand volumes and tactical decisions have more impact on smaller warehouses. However, in smaller warehouses, the operational level decision does not influence the performance as much as tactical decisions. Because of this, decisions made for smaller warehouses benefit from focusing on tactical levels where the most impact is achieved. Optimizing operational details will have marginal results and is not considered worth the effort (Koster et al., 2007).

A standard for handling products in a supply chain has emerged through years of practice. The packaging system is generally divided into three levels of decreasing size and proximity to the actual product: tertiary, secondary, and primary package. A tertiary package is often a pallet. This is the largest quantifiable unit that the supply chain handles. The secondary package can be a carton or a case containing some set amount of products. Lastly, the primary package is the one that the end customer sees in a retail store (Bartholdi & Hackman, 2014). From a productional warehouse, finished goods typically get packed using the largest handling unit. For a distributional warehouse, its customers may be another production facility, so the products are shipped using tertiary packages. If an actor's product is a sub-product of another product, the end customer will not see the primary package but the one for the second actor instead. The product is unitized in amounts that fulfill the end customer's demand (Saghir, 2004). The end customer can evidently be viewed differently depending on the actor's perspective. The tertiary, secondary, and primary packaging levels often correspond to their SKUs in the warehouse. These handling units need to be managed appropriately and determine what equipment is used. Furthermore, as the material flow dictates the design of a warehouse, this is true for the aspects of SKUs. If a warehouse handles multiple packaging levels, the same warehouse is likely to need many different handling equipment to facilitate the actions (Bartholdi & Hackman, 2014; Mantela et al., 2000). A unit load is a term used to describe the quantity in which the products are transported, e.g. carton or pallet. When picking, the quantity is generally less than the unit load (Gademann et al., 1998).

3.2.6 Storage- and handling equipment & automation- and information systems

To further facilitate better space management and lower labor costs in the warehouse, some equipment for storing and handling is almost always used in a warehouse. These are racks and trucks that have previously been touched upon but will now be explained more. Considering racks, there are mainly four different variants used with varying intents. The different racks and their unique functions are suited for different situations. These are listed in table 3.3. The selection of racks is dependent on floor space, flexibility, and inventory management (Bartholdi & Hackman, 2014; Frazelle, 2002).

Table 3.3: *Different types of racks.*

Racks	Function	Suitability
Single deep	One position deep storing.	Is suitable for FIFO, the most common

		solution, and fits with all trucks.
Double deep	Two-position deep storing, two single racks combined.	Is suitable for LIFO as the racks can only be accessible from one side.
Push back	Extension of the double deep rack.	Is suitable for LIFO as the racks can only be accessible from one side.
Flow-through	Deep lane with rollers and an inclination that pulls the pallets down.	Is suitable for FIFO and both truck and hand picking, best for a limited number of SKUs with large volume.

The type of truck used is most often determined by the type of rack, but also the weight of the load. In table 3.4 five of the most common alternatives are presented (Bartholdi & Hackman, 2014; Frazelle, 2002).

Table 3.4: *Different types of trucks.*

Truck	Function	Suitability
Counterbalance	Versatile	For heavy loads.
Forklift	Extendable forks	The most common one is best for short distances. Electric with a platform to stand on.
Turret	Turning 90 degrees	For narrow aisles or corners.
Hand pallet jack (manual or electric)	Moved manually	Only for floor-based storage, space-efficient.
Wagon	Moved manually	For cartons and small SKUs to be put on the wagon by hand.

Today, most warehouses use a digital system, whereas the most used are ERP system and WMS. An ERP system can handle long-term planning and manage information regarding sourcing, human resources, and more. A WMS typically focuses on short-term planning, controls inventory, manages storage locations, creates pick-lists, allocates goods, and manages staff. There are different types of WMS, and depending on the specification, which differs between warehouses, it will have different abilities. Both a WMS and an ERP system can be used to share information with each other or other systems (Kembro & Norrman, 2019b; Bartholdi & Hackman, 2014; De Koster et al., 2013). Harb et al. (2016) investigated a private company and found that locations became clear and well defined when implementing a WMS compared to the previous crowded warehouse. There was also a much higher accuracy in-stock level reporting. Furthermore, a WMS can help solve manual task problems and incorrect storage locations (Anđelković and Radosavljević, 2018). It also presents opportunities to adapt the operations to your context by introducing storage policies based on, e.g., weight, shape, or First In First Out (FIFO) (Wang, 2010). Companies that have chosen not to implement a WMS in their warehouse are at a competitive disadvantage and are less prepared for changes in customer demand. A

WMS can also have add-ons as physical products, such as scanners, to scan barcodes on products. Besides being near-perfect accuracy, scanners also enable workers to work faster and enable real-time monitoring of warehousing operations which is substantially more difficult to achieve with manual data input. All of this reduces time in the picking process, which is highly important as it, as mentioned, is the most time-consuming activity in the warehouse (Faber, 2002; Baruffaldi, 2019).

The degree of warehouse automation is rapidly increasing. Although it is expensive to invest in and requires capital, automation brings several benefits. For example, it reduces operational costs while increasing the possibility of storing a wide range of products. It also enables faster throughput and flexibility in handling different types of products and activities (Azadeh et al., 2019; Holzapfel et al., 2016). However, the more automated, the better is not always the case. Companies that benefit the most from automation have high turnover, a large number of total SKUs, and high total throughput. It is also more feasible to automate smaller goods and standardized packages. Historically, demand variation has been an important factor, but as automated systems become more flexible, this factor is not the same barrier to investing in automation solutions (Kembro & Norrman, 2021; Baker & Naish, 2004). Baker & Naish (2004) explain how manual labor includes picking from racks by hand or pallet lifter. Mechanical assistance might be needed if the number of SKUs rises. It includes motorized forklifts to put pallets into rack systems or conveyors to assist transportation. With even higher throughput, simple automation might be suitable, including Automated Storage and Retrieval Systems (AS/RS) for specific unit-loads such as cranes in a pallet-in-pallet-out warehouse and conveyor systems. Complex automation systems are suitable with high throughput and a high number of SKUs. These are often pick-to-person systems with a built-in sorting function and complex conveyor systems. This is shown in figure 3.8.

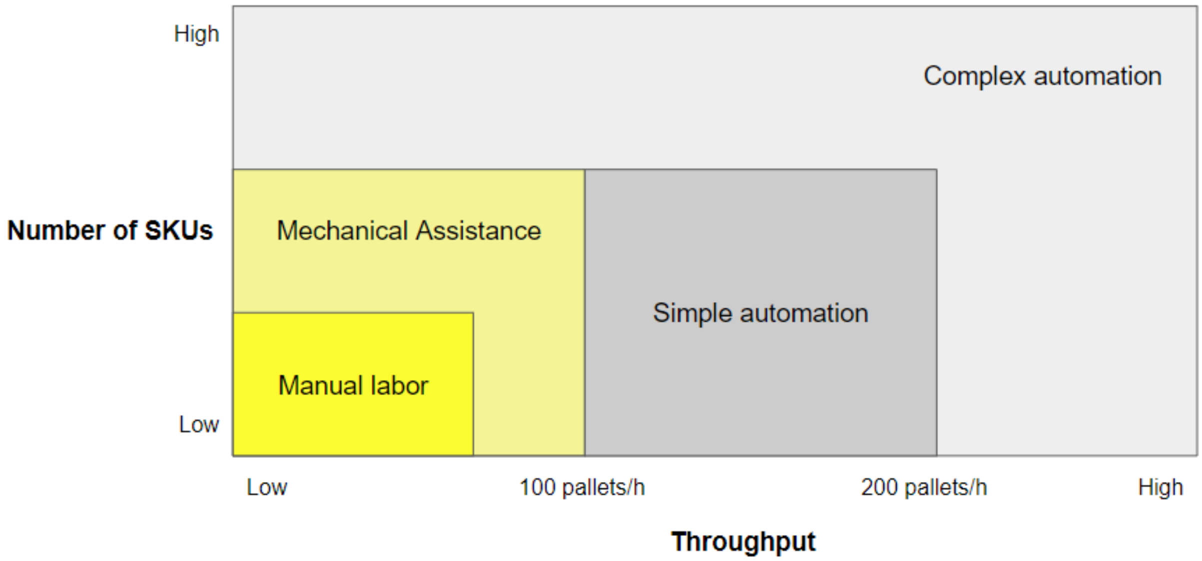


Figure 3.8: *Automation based on the number of SKUs and throughput (Baker & Naish, 2004).*

3.3 Prior researched frameworks for warehouse design

Frameworks for warehouse design are old. Nearly fifty years ago, Heskett et al. (1973) captured the main aspects of warehouse design using three areas. These were; determining the requirements, configuring systems for material handling, and creating the design. In most research afterward, these three steps are present. Baker & Canessa (2009) describes how frameworks proposed before the 2000s use, on average, just below seven steps, whereas the frameworks from 2000 and forward used almost ten steps. The frameworks have become more specific and elaborated so that a practitioner or researcher has clearer directives. Older frameworks and the most recent agree on four matters of warehouse design.

1. Frameworks are hard because the design process is complex.

2. The framework uses step-by-step approaches.

3. The steps are interrelated, and the design process needs to involve reiteration to some extent.

4. The "optimum" solution cannot be found due to the high number of possibilities and variations from every step of the design process.

There exist some frameworks for network design towards fast-growing companies. An example of such a framework is the one developed by Geuken & Jäger (2015) in their master thesis. They discovered that essential aspects are growth expectations and flexibility. Geuken & Jäger (2015) further developed a framework that focuses on growth of companies and the logistical consequences towards the warehouses of these companies. The scientific articles on fast growing companies in the development of frameworks for - or warehouse design in general are however scarce. For the purpose of this thesis, the framework of Geuken & Jäger (2015) will not be adapted and only be used as comparison as it is a master thesis and not as reviewed. Instead three of the most found frameworks for warehouse design will be adjusted to fit a fast-growing company in the creation of a new conceptual framework. The three frameworks for warehouse design are shown in table 3.5 and are described briefly below.

Mantela et al.: The framework is a classification of warehouse design and control problems. It aims to design or redesign a warehouse or a warehouse subsystem. The process of warehouse design passes a set of consecutive phases. On this matter, they agree with previous research. However, their addition or modification is that they group the activities within the phases into a framework of hierarchical order. The framework use a top-down approach and identify strategic, tactical, and operational decisions that should be considered in sequence (Mantela et al., 2000).

Hassan: The framework is suitable for many situations as the steps cover all aspects of the warehouse design. It can facilitate the task for both designers and managers. The framework is, in some ways, an extension of earlier frameworks, even if it mainly focuses on the layout of the warehouse design (Hassan, 2002).

Baker & Canessa: The framework is built on literature of warehouse design methodology, complemented by literature of specific tools and techniques applicable for areas of optimization and analysis. It is created from six previous frameworks, of which two are Hassan (2002) and Mantela et al. (2000). Comparing many authors yielded some commonly used steps that were thought to be valid for the new framework. The results presented have been validated and improved in conjunction with companies that specialize in warehouse design (Baker & Canessa; 2009).

Table 3.5: *Comparison of previous frameworks.*

Step	Mantela et al. (2000)	Hassan (2002)	Baker & Canessa (2009)
1	Define concept	Specifying the type and purpose of the warehouse	Define system requirements
2	Acquire data	Forecasting and analysis of expected demand	Define and obtain data
3	Produce functional specification	Establishing operating policies	Analyze data
4	Produce technical specification	Determining inventory levels	Establish unit loads to be used

5	Select the means and equipment	Class formation	Determining operating procedure and measures
6	Develop layout	General layout	Consider possible equipment types and characteristics
7	Select planning and control policies	Storage partition	Calculate equipment capacities and quantities
8		Material handling, storing and sortation systems	Define services and ancillary operations
9		Configuration of aisles	Prepare possible layouts
10		Determining capacity requirements	Evaluate and assess
11		Number and location of I/O ports	Identify the preferred design
12		Number and location of docks	
13		Arrangement of storage	
14		Zone formation	

4. Conceptual framework

This chapter is the link between litterature review (chapter 3.3) and RO1 to formulate a new conceptual framework to match the capacity requirements of a fast-growing company. It is made by beginning with understanding the requirements to fit the aim for a fast-growing company using theory and information from Mips and then applying that information to the previously developed frameworks for warehouse design in 3.3. It leads to a conceptual framework with six steps that later on are applied to Mips.

4.1 Understanding requirements for a fast-growing company

The new conceptual framework should follow the aim of the thesis and focus on DC design to match the capacity requirements of a fast-growing company. Three requirements are developed to facilitate this, using a combination of theory and Mips experience.

1. It is hard to forecast based on the previous demand of a fast-growing company (Carson et al., 2013). Mips has therefore suggested forecasting using scenarios, which can be seen as forecasting with people's opinions. The scenarios can cover aspects that cannot be found in data, such as products to be introduced/removed, predicted growth based on decisions only stakeholders within the company know, etc. The thesis aims to match the capacity requirements of a fast-growing company, which is why demand is a crucial aspect. Scenarios will be developed to forecast future demand.

2. As design in this thesis refers to; layout (aisle, lane depth, etc.), storage equipment (types of racks, etc.), handling equipment (types of forklifts, etc.), automation solutions (scanners, etc.), and information systems (WMS, ERP, etc.), these decision areas must be included in the new conceptual framework. Smaller warehouses benefit most from decisions on a tactical level, such as; layout configuration and the dimension of the storage system, assignment of products to storage locations, etc. (De Koster et al., 2007). As Mips warehouse can be seen as a smaller warehouse, less focus will be put on handling equipment, automation systems, and information systems.

3. As fast-growing companies often are small and the organizations might be in the growth phase and still developing the strategy, Mips suggests that a framework that has few steps is more practical in implementation. Fewer steps are easier to adjust to the company's situation and possible for employees that aren’t that experienced to handle. Since iteration among the steps is advisable, it is also considered more practical with fewer steps because it makes the framework more iterable. The interrelationships between the steps will be more apparent this way which is beneficial according to the reviewed frameworks (Hassan, 2002).

4.2 Review of steps in the prior researched frameworks and theory

The prior researched frameworks differ in the number of steps and what the steps are. Mantela et al. (2000) have a framework open for the user to configure in a preferred way since it consists of a few steps. However, it also makes it less specific. Hassan's (2002) framework is wide and focuses on many areas and situations, making the result less specific. Baker & Canessa's (2009) framework is thoroughly evaluated from seven other frameworks but focuses on the definition and evaluation parts. The steps that the researchers found were similar and useful based on the theory are highlighted in the same color in table 4.2, with the ledger in table 4.1. The existing frameworks of Hassan (2002), Baker & Canessa (2009), and Mantela et al. (2002) are reviewed from which steps considered important, according to theory in the case of a fast-growing company, are chosen for further review. A concept is generally extended to the proposed framework if it is either: 1 - present across the prior researched frameworks, 2 - if it is emphasized in theory, or a combination of them.

4.2.1 Initial steps

Through every framework, the initial step is very similar. The strategy is important to consider since it dictates much of the criteria that will be used to design the warehouse (Bozer et al., 2010; Mantela et al., 2000). The warehouse strategy imposes different criteria for throughput, space utilization, or assignment policy. Furthermore, the warehouse's objective regarding what markets it will serve or the possibility of value-adding activities is beneficial to include early in the design process because of its subsequent impact on later steps (Hassan, 2002). For this reason, the first step will be a combination of these three where the current situation is mapped which includes specifying the type and purpose of the warehouse and what operational implications it has for the warehouse. For example, Hassan (2002) suggests that this step provides the practitioner with a conception of the expected levels of operation and design criteria for the warehouse (Hassan, 2002). Steps in light blue are related to this concept in table 4.1.

4.2.2 Scenarios for fast growing companies

With the background of the reasoning in the first section from 4.1 (understanding requirements for a fast-growing company), the lack of steps that includes scenarios for the warehouse is clear. In a fast-growing company, the three presented former frameworks do not cover the benefits of a scenario breakdown which is a requirement from Mips' side. Even though it could be interpreted that such a method should be implemented through any of the steps in the frameworks, it is believed that this concept requires its step since it is a big part of the solution for a framework aimed at fast-growing companies. Again, choosing steps that are both motivated in theory and formulated for practical implementation is crucial and inspired by Hassan's (2002) framework, which has more explicit steps than a few broad and abstract ones. This is related to requirement 3 in section 4.1 (understanding requirements for a fast-growing company).

4.2.3 Forecasting, expected demand and inventory levels

The second step of Hassan's framework is *forecasting and analysis of expected demand*. Mantela et al. (2000) and Baker & Canessa (2009) have more abstract steps of data acquisition and data. Demand is involved in the steps, but for the framework to suit practical implementation beyond research purposes, the steps should be clear and concise. Since the demand for a product is the direct dictator for the space requirements for warehousing, this step is viewed as crucial in the framework and should not be a substep either. (Mantela et al., 2000; Goetschalckx et al., 2010). How the demand behaves is a connection to where a product or company exists in the life cycle, which is why this step fits together with the first step specifying the type, purpose, and in turn, its strategy in the first step (Cox, 1967). It is key to understand the demand and its characteristics to correctly align the supply chain and warehouses to the strategy (Fisher, 1997; Lee, 2002). The light gray steps in table 4.1 cover this concept. As mentioned, it is only Hassan's framework that highlights this. Ultimately in a warehouse, the flow of goods will mean that the inventory levels will behave specifically. Mantela et al. (2000) have a step that produces functional specifications, and Baker & Canessa (2009) have established unit loads to be used. Ultimately, the aim of the steps is determining the inventory levels. This is a step that Hassan (2002) has explicitly included *4.2 determining inventory levels*. The inventory decisions affect subsequent steps regarding space allocation and storage partition and should beneficially be analyzed simultaneously (Hassan, 2002). This suggests that the topics should either be in the same step or closely related steps. Also, this concept is highlighted in table 4.1 with light cray because of its close relation to the demand for products. However, the steps in dark green are a part of the process, according to the researchers.

4.2.4 Layout

Some of the later steps in all of the frameworks cover areas related to layout. These are formulated similarly, such as *6.1 develop layout* (Mantela et al. 2000), 6.2 *general layout* (Hassan 2002) or 9.3 *prepare possible layouts* (Baker & Canessa 2009). According to Mantela et al. (2000), the most space-requiring process is the storage of products. The operation flow within the warehouse is partly determined by the layout and the storage policies applied to the chosen layout. The shared- or dedicated storage policy-related decisions will have implications for the amount of administrative work, flexibility in the warehouse, and the faults in operation (Mantela et al., 2000; Bozer et al., 2010). All of the frameworks emphasize layout, which suggests that a framework must contain this, however only Hassan's (2002) framework incorporates *5.2 class formation, 7.2 storage partitioning, 9.2 configuration of aisles* and *13.2 arrangement of storage* as well which are emphasized in theory as important factors that greatly influence the warehouse. These are all grouped in dark blue in table 4.1

4.2.5 Physical equipment and digital solutions

Another topic, as suggested by all of the frameworks, is the step of determining what equipment and systems should be used in the warehouse. In Mantelas et al. (2000) is *step 5.1 select the* *means and equipment. In* Hassan's (2002) it is *8.2 material handling, storing and sortation systems*, and in Baker & Canessas (2009) it is *6.3 consider possible equipment types and characteristics*. The theory also concurs that equipment for storing and handling in a warehouse facilitates better space management and lowers labor costs (Bartholdi & Hackman, 2014; Frazelle, 2002). Furthermore, digital systems within warehousing are widely covered, and it is established that companies without implemented WMS are at a competitive disadvantage. They are less prepared for changes in customer demands which for a growth company is more volatile (Faber, 2002; Baruffaldi, 2019). According to Hassan (2002), the decisions regarding tools of material handling and storage systems should be considered in close relation to the warehouse layout because of its interrelation with space requirements, storage assignments, and flow in the warehouse. This suggests examining material handling and storage in conjunction with layout analysis, either in the same step or closely after. Steps in the frameworks related to these concepts are highlighted in table 4.1 as dark gray.

4.2.6 Summarizing step

Ultimately in a framework for warehouse design, the proposed solution should be highlighted. Baker & Canessa's last step is *11.3 identifying the preferred design.* A similar step is not found in Hassan's framework (2002) nor in Mantela's et al. (2000). The step draws together the previous elements into a coherent design, including unit loads, operational flows, equipment and information systems, the layout, size of the warehouse, staffing, and total costs. Without such a step, practitioners will be left with the partial results from the previous steps and not connect everything finally (Oxley, 1994). Baker & Canessa (2009) also mentions that both quantitative and qualitative methods can be used during the last step of creating, for example, a financial business case or a SWOT analysis of the proposed solution to assess its suitability for its purpose. As mentioned Baker & Canessa (2009) are unique in having this step, and it is highlighted using green in table 4.1

4.2.7 The similarities and differences in prior researched frameworks

The steps in the frameworks that do not have any similar steps are white in the frameworks in table 4.1. As it is not highlighted as especially important in theory to *establish unit loads to be used, select planning and control policies, define services and ancillary operations, evaluate and assess and number and location of I/O ports*, these steps are seen not be helpful in the creation of a new conceptual framework.

Table 4.1: *Ledger.*

No similar steps	Forecasting and inventory levels	Current situation	Proposed solution	Layout	Data analysis

Table 4.2: *Prior researched frameworks and highlighted steps.*

Mantela et al. (2000)	Hassan (2002)	Baker & Canessa (2009)
1.1: Define concept	**1.2:** Specifying the type and purpose of the warehouse	**1.3:** Define system requirements
2.1: Acquire data	**2.2:** Forecasting and analysis of expected demand	**2.3:** Define and obtain data
3.1: Produce functional specification	**3.2:** Establishing operating policies	**3.3:** Analyze data
4.1: Produce technical specification	**4.2:** Determining inventory levels	**4.3:** Establish unit loads to be used
5.1: Select the means and equipment	**5.2:** Class formation	**5.3:** Determining operating procedure and measures
6.1: Develop layout	**6.2:** General layout	**6.3:** Consider possible equipment types and characteristics
7.1: Select planning and control policies	**7.2:** Storage partition	**7.3:** Calculate equipment capacities and quantities
	8.2: Material handling, storing and sortation systems	**8.3:** Define services and ancillary operations
	9.2: Configuration of aisles	**9.3:** Prepare possible layouts
	10.2: Determining space requirements	**10.3:** Evaluate and assess
	11.2: Number and location of I/O ports	**11.3:** Identify the preferred design
	12.2: Number and location of docks	
	13.2: Arrangement of storage	
	14.2: Zone formation	

4.3 Formulating a new conceptual framework for distribution center design to match the capacity of a fast-growing company

As can be seen in table 4.1 many of the steps in the previous frameworks are concerning the same areas and is therefore possible to group based on its color-coding. Requirements 3 also highlights how fewer steps are an advantage for fast-growing companies to use. It is therefore done in the creation of the new conceptual framework for a DC design to match the requirements of a fast-growing company. The new conceptual framework is divided into 6 steps where step 2 is adapted from the requirements of a fast-growing company in 4.1, and the rest of the steps are adapted from the previous frameworks in table 4.2. A description of the background of each step can be seen below and in table 4.3 a description of each step can be seen together with its application in a fast-growing company.

Step 1 is mapping and understanding the current situation. It is an area that is highlighted as important in the literature of Higginson and Bookbinder (2005) and Glaskowsky et al. (1973). It is also a combination of the steps in light blue in table 4.1.

Step 2 is scenarios, assumptions & simplifications. The scenarios are requirement 1 for a fast-growing company and, as mentioned, a way of forecasting capacity. Assumptions and simplifications are included to strengthen the confirmability of the result.

Step 3 is capacity. It combines steps from the previous frameworks highlighted in light gray. The steps in medium blue are used to obtain and understand the data leading to capacity requirements. It also uses the scenarios determined in step 2 to forecast.

Step 4 is layout. It is a part of requirement 2 for a fast-growing company and a combination of the steps in table 4.1 highlighted in dark blue.

Step 5 is equipment & automation- and information systems. It is also a part of requirement 2, and a combination of the steps highlighted in dark gray in table 4.1

Step 6 is the proposed solution. This is based on the highlighted green step 11.3 in table 4.1, *Identify the preferred design*. It is a reconnection of previous steps in this framework to end up with a final proposed solution.

Table 4.3: New conceptual framework for DC design of a fast-growing company.

Step	Description	Application at a fast-growing company
1: Current situation	Mapping of the type of warehouse and its characteristics. The company strategy links to the warehouse. Information regarding the SKUs. Operations within the warehouse.	Important in order to understand the context of a fast-growing company as well as any other company.
2: Scenarios, assumptions & simplifications	Areas and alternatives are explained, and the scenarios they lead to. Assumptions and simplifications that are used later on in the framework are explained.	For a fast-growing company, it is harder to forecast, and scenarios can be a way to understand what the company can face while growing. Assumptions and simplifications are useful to strengthen the confirmability of results for fast-growing companies as well as for other companies.

3: Capacity	High and low demand items.Trends and seasonality. Forecasting and analysis of expected future demand. All of this determines the capacity requirements of the warehouse in terms of floor space. Acquire and analyze data.	A crucial step to match space requirements with growth.
4: Layout	Class formation. FPA and reserve areas. Warehouse departments. Amount, dimension, and location of aisles. Number of docks.	Important for fast-growing companies as well as other companies. The decisions within this step will however be based on that the company is fast-growing.
5: Equipment & automation- and information systems	Storage equipment. Handling equipment. Level of automation and information systems.	Important for fast-growing companies as well as other companies. The decisions within this step will however be based on that the company is fast-growing
6: Proposed solution	The outcomes of previous steps together create the proposed solution. The scenarios in step 2 analyzed and connected to the company's strategy.	This is the proposed solution for a fast-growing company taking all aspects into consideration.

A graphical representation of what each step in the new conceptual framework leads to can be seen in figure 4.1.

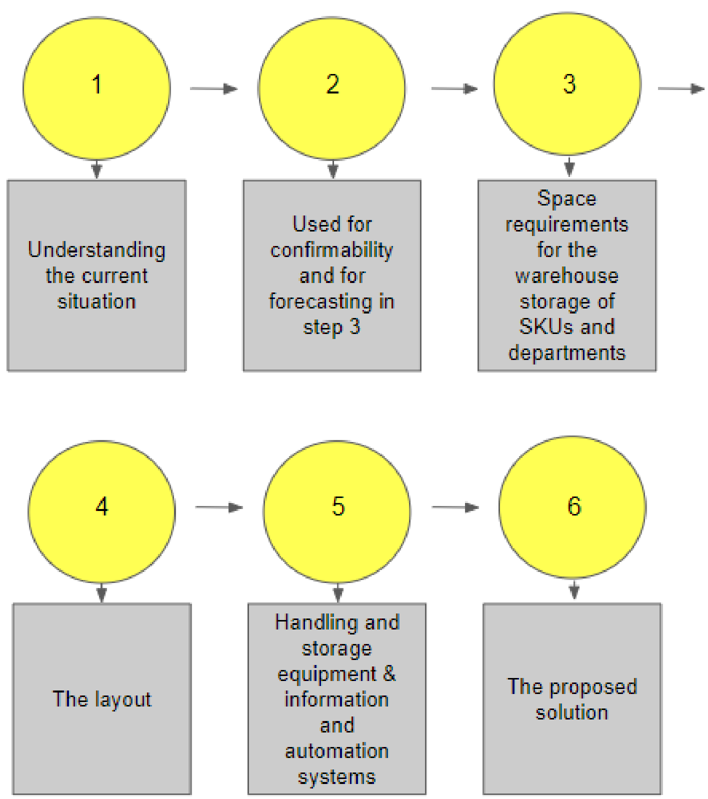


Figure 4.1: *The outcome for each step of the conceptual framework.*

5. Applying the conceptual framework at Mips

This is RO2, which means that the new conceptual framework developed in chapter 4 here is applied at Mips. Each of the six steps in the frameworks is used, and a summary of the key takeaways from each step concludes each subchapter. The information in this chapter is based on interviews with employees and correspondence when nothing else is stated.

5.1 Current situation

The current situation is referring to the products and their packaging information, MCW characteristics, Mips strategy, and growth. The information is gathered from interviews and correspondence with Mips, and it is used in calculations and analyses in further steps in the conceptual framework.

5.1.1 Products & packaging information

The products are categorized as generic products (products that are used in many customer orders) and LFLs (Low Friction Layers, which are custom made). Packages are interchangeably referred to as cartons, which are the secondary packaging within the operations. Pallets refer to the tertiary packaging. The generic products are kept in safety stock while the LFLs are made to order. Only some LFLs are kept in safety stock in case a customer needs them very urgently. The product packaging information for the products in MCW can be seen in table 5.1.

Table 5.1: *Product packaging information.*

Type	Subtype	Number per package	Number of packages on pallet
Generic components	Sliding enabler	52227 (average)	25
	Snap-pin Snap-pin (yellow)	120000 12000 (yellow)	30 30 (yellow)
	Rubber fixation	30000	30
	U-shape	150000	30
	Hangtag (average)	3633	33
	Box label	25000	20
	Hologram sticker	250000	30
LFL concept	A	600	23
	B	160	25
	C	200	34
	D	120	23

	E	160	23
	Integra	120	23

5.1.2 Mips China Warehouse

Size and activities

The current MCW is $800m^2$ (areas including office space etc. takes up additionally $386m^2$). In MCW, there are 23 employees, the majority of them working in the warehouse and at Quality Control (QC). Mips has a production lead time of 45 days from when Mips receives an official order from the helmet brand to when it leaves MCW. The production starts after the helmet has passed an approval test in Sweden. The approval test is an internal quality assurance that makes sure that the helmet is mounted according to Mips assembly specification, that the solution satisfies the criteria of significantly reducing multi-directional impact, and that no modifications will be made on either the LFL or Expandable Polystyrene/Expandable Polypropylene (EPS/EPP), a styrofoam inner part of the helmet afterward. When the LFL arrives in MCW it takes three days up to a month until they are sent to customers. During that time, a quality control (QC) is performed at all boxes where they are opened. Depending on the priority, they are either packed directly after and put on the shipping dock or stored if it has lower priority. The generic parts also pass through QC when arriving but are then stored and picked by FIFO principle.

Operational characteristics

MCW is a DC with a combination between pick-up and delivery, cross-dock/consolidation, warehouse, and to some extent break bulk. The main focus is to handle orders from suppliers and consolidate them to customers but also warehousing with safety stock. No value-adding activities are performed in the warehouse. The purpose is to provide the customers with the best service, by having safety stock if they need it urgently, having quality controls, and best possible service level. Because of this, it is important to never run out of stock. Covid has been an issue, prompting the company to have 3-4 months of safety stock of generic components instead of 1-2 months previously. Small orders contain one pallet while big orders have 20-30 pallets, each pallet has a size of 1.2x1.0m^2 and an initial height of 1.65m before QC. The large orders depart roughly 3 times per month while small ones 3 days per week. All cartons are shipped on pallets and several types of products can be stored on the same pallet. There are 3 wagons (1m turnaround area), 1 forklift (turnaround of 3m), 1 electric hand pallet jacks (turnaround area of 1.5m) and 3 manual hand pallet jacks (turnaround area of 1.5m) to handle the movement of, SKUs. MCW has 50 racks with a dimension of 2x2x0.4m against one wall. They each have 4 floors with space for 10 cartons on each. The racks hold LFLs of smaller volume that are picked by hand, the racks take up approximately $100m^2$. The racks are single deep and cartons are picked by FIFO. There is currently only one dock for deliveries and shipments, but the wide deck enables several trucks to operate simultaneously. The current storage method used in MCW is mainly floor storage with cartons on pallets for both LFLs and generic components. Following safety restrictions in China a main passageway, fire passageway, is $3m$. A general passageway, such as between areas, is $1.5m$ and the pedestrian passageway, such as between shelves, is $0.5m$.

Digital level

Mips does have an ERP system but no WMS, however, it would be possible to add one to the current ERP system. Mips uses an ERP system but most of the data is put in it manually. Manual inventory is made every month and the ERP system does not store the position the SKUs are kept on. Article numbers and labels are printed and put on cartons manually. Delivery notes from suppliers are signed when the count is ok and delivery notes to client factories are signed and checked if the count is ok.

Warehouse areas

The current warehouse is divided into three areas. The first one is where the storage of SKUs, both LFLs and generic components, is located. It includes entrance, shipping, QC, etc. Then there are other area within the warehouse that do not store any SKUs, such as the room for equipment, workshop, confidential storage area, etc. These two areas together create what is referred to as the warehouse storage area. Lastly, there is the area used for the employees, such as offices, meeting rooms, etc. Referred to as other areas. The three divisions of areas are calculated individually and differently. A further description of these areas can be found in 5.3.4, areas within Mips China Warehouse.

5.1.3 Mips strategy & growth

Mips have a lot of power in designing their supply chain and have used that to put the responsibility on suppliers and customers. Mips is currently storing around 50% of its generic components at its suppliers, which is possible because of their excellent relationship. It has been beneficial during covid to have the inventory divided between several areas to hedge against issues with lockdowns. When the warehouse has been packed, Mips has solved that by storing more at their suppliers, performing the QC there, and then directly delivering to suppliers. However, it must be considered that this might change in the future, and Mips has to store up to 100% more generic components in MCW. The customers are in charge of the shipping and pick the right size truck depending on the number of pallets in their order. The supply chain is responsive, which means it produces to order and has a small safety stock. Mips are placed relatively in the center of Lee's (2002) figure, as shown in figure 5.1. The supply uncertainty is relatively low as Mips has several suppliers. It was, however, even lower before Covid, but according to Mips, it will stay like this for now. The demand uncertainty is relatively high because the model can be used for all types of supply chains. The lowest demand uncertainty has, for example, everyday products in grocery stores. Because of this, and they are both produced to order (LFLs), and to stock (generic components), Mips is placed in the low part of the high uncertainty box.

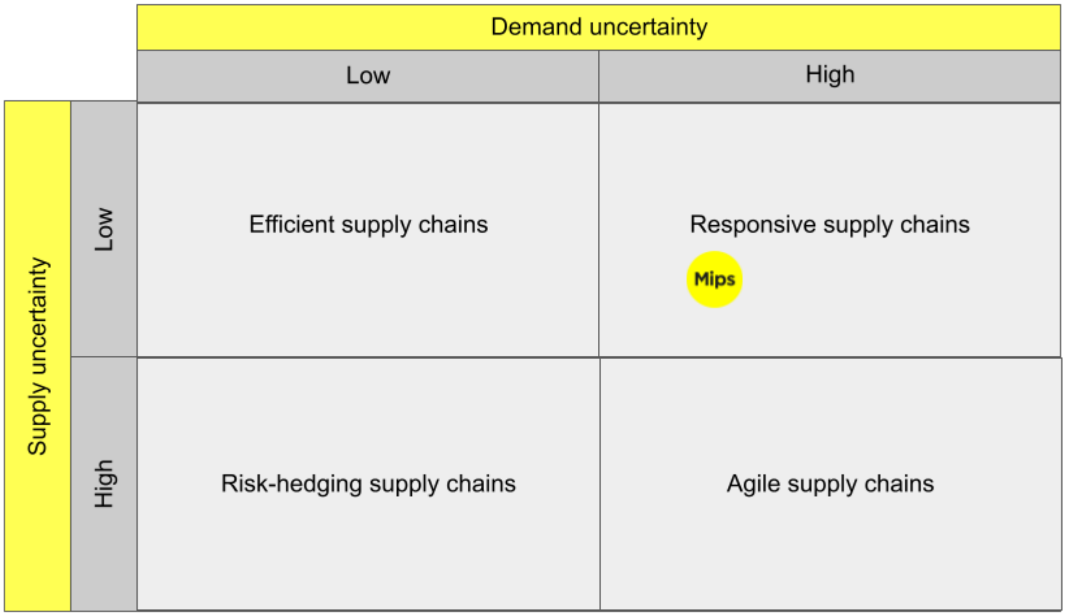


Figure 5.1: *Mips' position in Lee's (2002) figure.*

Mips' position in The business life cycle can be seen in figure 5.2. Considering that Mips is in the growth phase, according to theory probable that the company will continue to exhibit growth shortly. Using historical data and assuming the demand will be constant will under dimension the warehouse. However, using the past growth as an indication of future growth could be more relevant. Since Mips has been in the same state for a few years now, they have established product development and have their processes figured out and are skilled in this process.

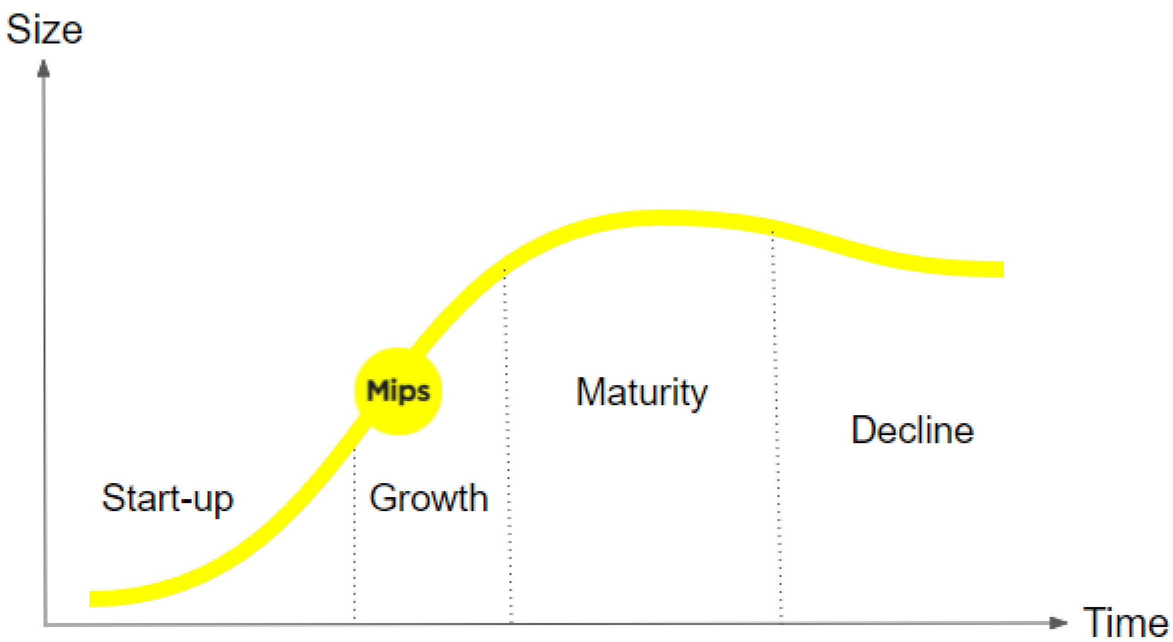


Figure 5.2: *Mips' position in The business life cycle (Theodore Levitt, 1965).*

5.1.4 Key takeaways

In summary, Mips has two product categories which are LFLs and generic components. The generic components are made to stock whilst the LFLs are made to order. The generic components are a lot smaller than LFLs and generally fit many more into a box of the same size. The warehouse facilitates the process of order handling from suppliers and consolidation to customers as well as warehousing safety stock for mainly generic components and some LFLs. The LFLs are quality controlled within the warehouse which means all boxes are unpacked and packed again. In their $800m^2$ warehouse area, Mips operates 3 wagons, 1 forklift, 1 electric hand pallet jacks, and 3 manual hand pallet jacks to handle the flow-through of goods. Mips can produce its products from different suppliers and has established good relationships with many of them. Because of this, they store a lot of their products at their suppliers after production. Their supply chain is responsive in the sense that they produce on-demand and their supply risk is low due to their multi-sourcing capability. Furthermore, Mips has matured beyond start-up, but they are still not saturated in the possibilities of expanding their product. This is strengthened by their continuous strong historical growth as well as projected future growth by themselves and others.

5.2 Scenarios, assumptions & simplifications

Possible scenarios that Mips can face during the next two years have been suggested and reviewed by the authors. Assumptions created in collaboration with Mips and used throughout the report are also displayed. The scenarios are used when calculating the actual floor space for storage in the warehouse and the scenarios and assumptions are also used in calculations in further steps in the framework.

5.2.1 Scenarios

The three areas of scenario generates a total of eight scenarios which can be seen in table 5.2. They are a combination of the aspects B volume inhouse, generic components stock inhouse and annual growth rate.

B volume inhouse is referring to the growth of the B LFL-concept. Either *All new volume inhouse, additional volume for 2022 and going forward will be 70% B-solutions. No B-project will be manufactured by the client factory* **or** *All B inhouse, additional volume for 2022 and going forward will be 70% B-solutions. All new B-projects will be started at Mips vendors and current B-projects at client factory will grow at the same rate as Mips total volume.* Generic components stock inhouse is a part of Mips' strategy of providing the customers with the best possible service level. The uncertainty in the world after Covid has led to Mips storing 4 or 6 months worth of stock of generic components. The 10% annual growth rate is Mips own forecast, but looking at previous years it has been much higher and 15% is therefore evaluated as well.

Table 5.2: *Scenarios.*

Area	10% annual growth from 12.5M 2021				15% annual growth from 12.5M 2021			
B volume inhouse	All new B inhouse		All B inhouse		All new B inhouse		All B inhouse	
Generic components stock inhouse, months	4	6	4	6	4	6	4	6
Needed warehouse area, m^2	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*	*Scenario 8*

5.2.2 Assumptions & simplifications

Packaging information, generic components: With information from sold quantities, there is accurate packaging information for 97% of the components. Both in terms of pieces per package and packages per pallet. The rest (3%) of the products are negligible and not used, they are also the ones that account for the least amount in the warehouse.

Packaging information, LFL: The LFLs are categorized into A, B, C, D, E, and Integra. Even though the packaging information will vary within the categories, a general specification is picked for the category as a whole. As such, it is not the most granular data, but it is more detailed than using only a single general specification.

Areas for employees: All the other areas not included in the warehouse storage such as office, gym, etc. is calculated assuming that each employee needs $20m^2$. For example, if there are 100 employees then all of the other areas have a total size of 20x100=$2000m^2$.

Employees in MCW: MCW will increase its number of employees to 25 by the end of 2024.

5.2.3 Key takeaways

The analysis will be based on a total of eight scenarios that are the result of three aspects; growth rates, inhouse storage partition, and the amount of kept safety stock. The generic components have detailed part-specific packaging information and the LFLs are specified into categories that are assumed to be representative of the actual distribution of varying packaging dimensions. For simplicity, areas other than the warehousing area itself such as offices or bathrooms will be calculated using $20m^2$ for a total of 25 employees by 2024.

5.3 Capacity

The size of the storage of SKUs in the new MCW, is calculated with the use of forecast, scenarios, changes in products, assumptions, and seasonality.

5.3.1 Inhouse/externally & stock keeping units added/subtracted

Historically, Mips have stored a majority of their LFLs at their suppliers with only a fraction of the LFLs going through their warehouse in China. Over time, this ratio has shifted as the LFLs have moved more through their warehouse. In 2017, less than 15% was inhouse, but by the year 2021, it had reached almost 50%. The future number is expected to increase, and the scenarios include different values to accommodate possible outcomes. The value of 2024 is a suggestion from Mips based on outsourcing and moving portions of their LFL to a European site instead. 2022 and 2023 is projected between 2021 and the 2024 forecast. Figure 5.3 shows how the amount of LFLs stored inhouse vs externally has changed and is expected to change in the future. The trend is kept in mind in the analysis, but only the number of 2024 is used in the analysis.

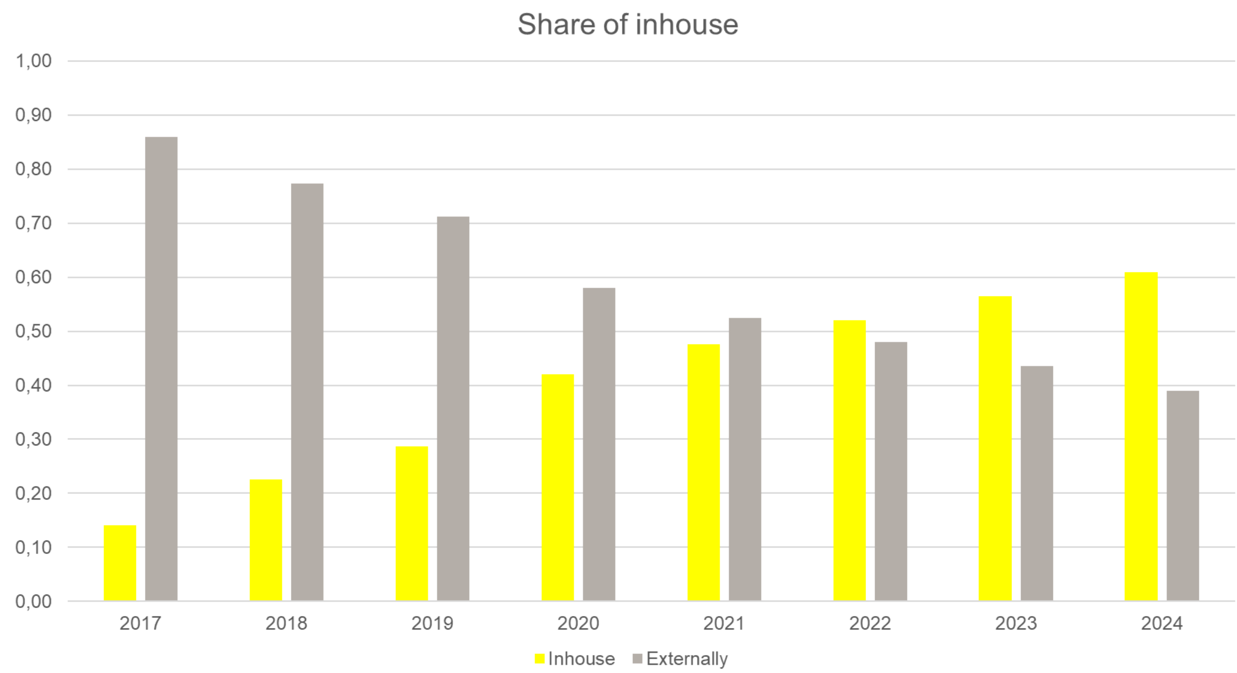


Figure 5.3: *Inhouse versus externally storage allocation 2024.*

In the future, some components will be removed while others will be added. See table 5.3 Components added/subtracted. For calculations, see appendix C.

Table 5.3: *Components added/subtracted.*

Type	Pallets 4 months 10%	Pallets 4 months 15%	Pallets 6 months 10%	Pallets 6 months 15%
Component 1	-48	-48	-71	-71
Component 2	-13	-13	-20	-20
Component 3 and component 4	+1	+1	+1	+1
Component 5	+2	+2	+3	+3
Component 6	+1	+1	+2	+2
Component 7	+1	+2	+2	+3

5.3.2 Seasonality, peak to average & forecasting

Looking at the sales data for the last five years, the peak to average ratio is shown in figure 5.4. The data shows a trend toward more volume in the latter part of the year, which corresponds with interviews with Mips telling that they have the most stocked warehouse in Q3 and Q4. To choose a peak to average for usage in forecasting, an average was taken from the highest peak of each year. This results in a peak to average of 1.67, which is used for further calculations in 5.3.5, a combination of all factors leading to actual space requirements.

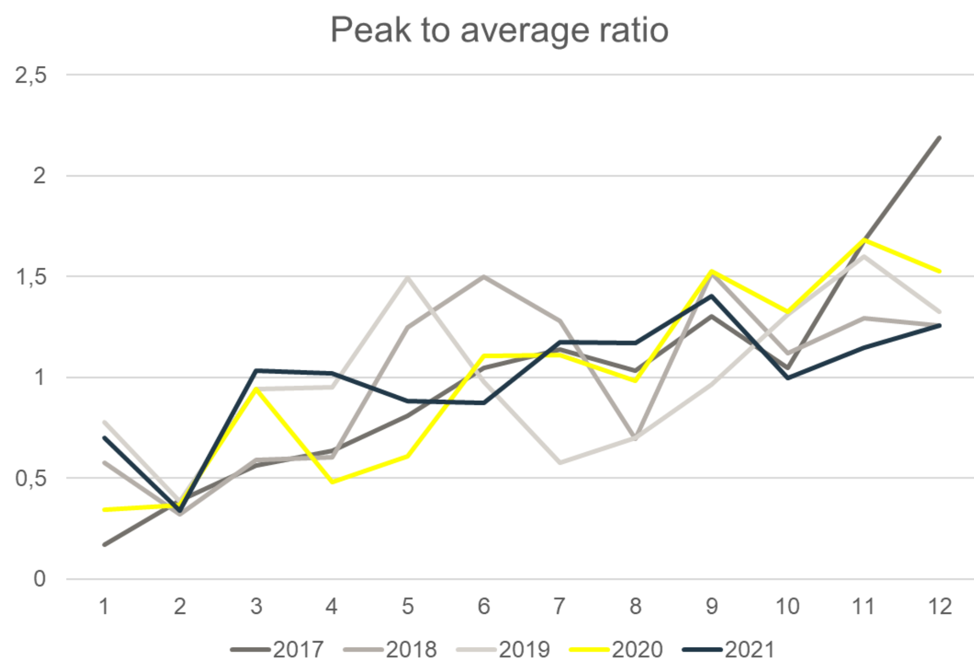


Figure 5.4: *Peak to average ratio, monthly per year.*

Based on the packaging data showcased in 5.1.1, products & packaging data, the yearly demand is expressed in terms of SKUs in figure 5.5. The white to gray colors indicate historical data, while the color is a projected future demand. The forecasted demand is divided into two annual growth rates, as highlighted in 5.2.1, scenarios. Every pair shows the total demand in conjunction with the actual internally stored number of pallets for that year. The distinction between internal and external storage is what is explained in 5.3.1, inhouse/externally & stock keeping units added/subtracted.

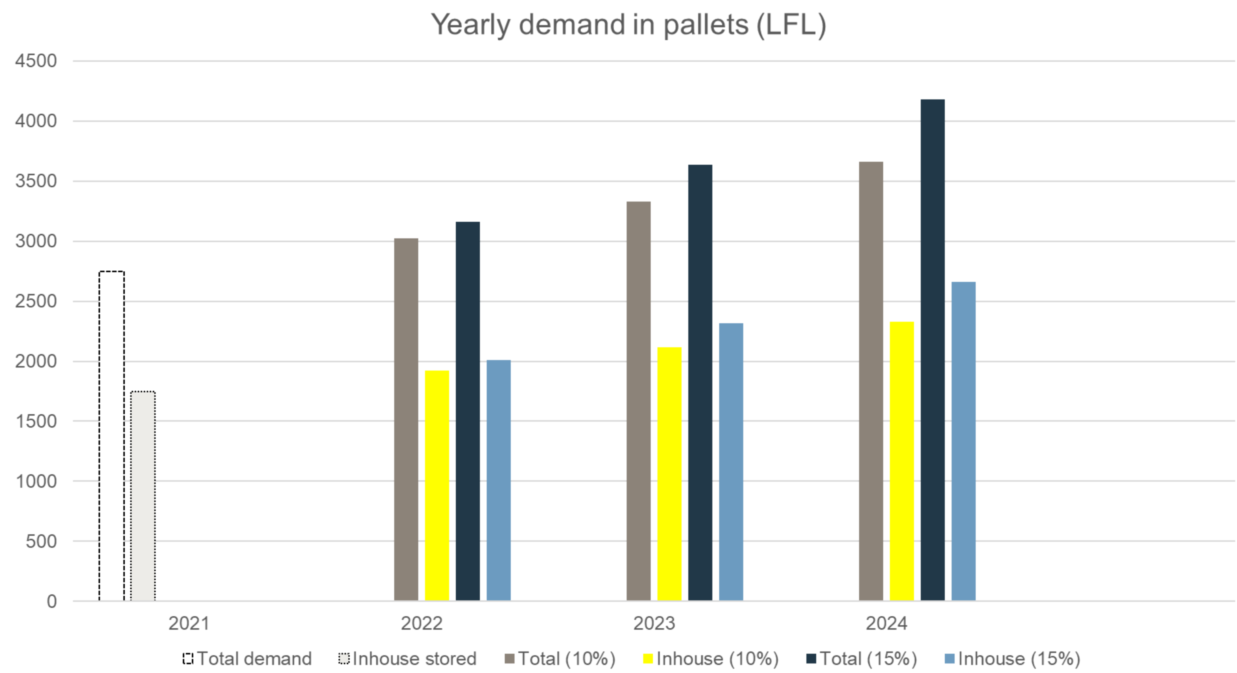


Figure 5.5: *Yearly demand of LFLs.*

Again, based on the packaging data in 5.1.1 and scenarios in 5.2.1, the yearly demand for generic components is expressed in figure 5.6. The figure shows the historical data as white while the future forecasted demand is colored. Multiple components are needed for one LFL in assembly, so even though the number of components is much greater, they correspond to the same amount of part kits. However, as expressed in pallets, components are fewer in that sense.

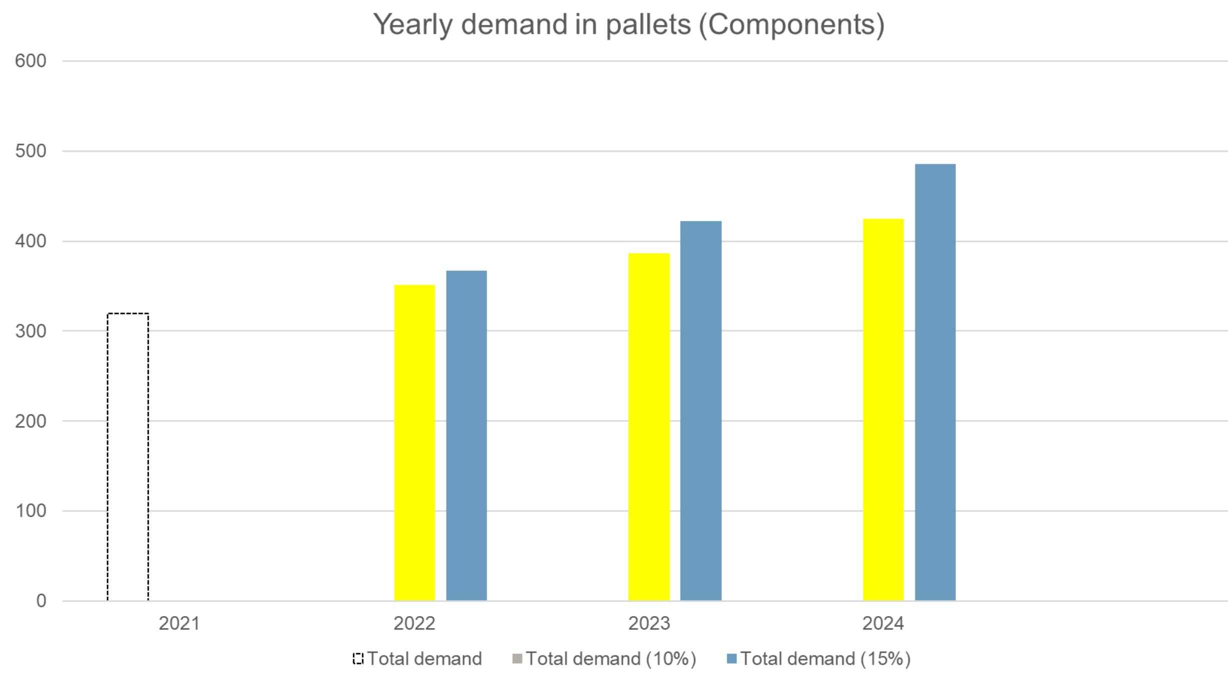


Figure 5.6: *Yearly demand of generic components.*

The numbers in scenarios are used because they are based on Mips' own forecast (people's opinion), which considers other aspects than just historical growth. Using only historical data to predict the future is believed to be less accurate than what employees know about the future of Mips. If the forecast was based purely on historical data, implications such as product introduction and other possibilities would not be considered. LFLs were forecasted by transforming the number of SKUs into pallets by packaging data for each concept. LFLs lay in the warehouse for 15 days because they generally are stocked 3 days to 1 month. Each concept was divided into the growth of inhouse storage. The growth rates were then used to forecast the amount. This led to four different scenarios with 10% or 15% growth and amount of inhouse storage. The forecasting of generic components was made from the historical sales data and projection two years ahead using said growth scenarios. This is considered the baseline of growth in distinction to the components brought up in 5.3.1, inhouse/externally & stock keeping units added/subtracted, which is an additional nuance to the figure of total generic components. The difference between them is, in essence, that the generic components exist today already and will likely grow along with the rate of the LFL, as referenced as the baseline. The additional components will be added to every LFL. This means that the number of components tied to a single LFL will not be static over time, but increase. Because of this, the baseline is not enough to cover the future components.

5.3.3 Pallet & floor utilization

From historical inventory data, the pallet utilization (fill rate) was 70% during 2021 when looking at the top 200 stored articles. Why only these were looked at because the others have such a low filling rate that they are consolidated to the same pallets or on racks. When including all the articles, the pallet utilization is 65%. However, 200 out of the around 1900 articles constitute nearly all of the pallets stored in the warehouse and batching of several SKUs on the same pallet is common. Therefore, the higher utilization rate of 70% percent of this category is chosen. The current utilization of floor space in the warehouse is 40%. It is calculated from inventory data regarding the average number of pallets in the warehouse in 2021 divided by the size of the warehouse that is used for storage based on a picture of the areas in the current warehouse. The same percentages are used in the calculation of the new warehouse since they are suitable numbers for the new warehouse as well in order to follow safety restrictions. The utilization of pallets and floor is used to transform a requirement in pallets into a requirement in the warehousing area.

5.3.4 Areas within Mips China Warehouse

The same departments Mips have in its current warehouse will be in the new as well with the same division between the three areas highlighted in yellow in table 5.4, explained in 5.1.2 Mips China Warehouse. The area in the warehouse used for storage of LFLs and generic components is calculated from inventory levels and scenarios. The area to be added separately to the warehouse storage area is the departments used for equipment and employees, which is calculated with information from Mips regarding the current size and predicted growth. Furthermore, there is the area that is calculated from the number of employees. Table 5.4 shows a summary of the areas with information about the departments within each area.

Table 5.4: *Areas within MCW.*

Warehouse storage area calculated with data of LFLs and generic components for capacity	
Area	**Description**
QC	Where each carton is opened and evaluated.
Entrance of goods	Where the goods arrive from suppliers with computers to register orders on.
Shipping area	Where the orders are stored for a short period of time before being shipped.
Stocking area	Consolidation area for storage for goods that have been packed but not rechecked regarding quantity. This is done here before the orders are sent to the shipment area.
Return area	For products that don’t pass QC to be stored before they are returned to the supplier.
Turnover area	For generic components that are only ordered when there is a consumer order of them.
FPA and reserve area	Storage of generic components.

Total area: See scenarios		
Warehouse storage areas in the warehouse calculated and added separately		
Area	**Description**	**Size**
Equipment	The ceiling must be at least 4,5m high.	$70m^2$
Tool placement	For forklifts and hand pallet jacks and eventually scanners.	$50m^2$
Packaging materials area,	Cartons, sealing paper, winding film, and other packaging materials needed.	$50m^2$
LFL sample room with passed LFLs.		See calculation in appendix C $150m^2$
Helmet sample room from customers.	Same as above.	Same as above $150m^2$
Reference room	For many years of archival storing.	$50m^2$
Confidential storage location	T1 development samples.	$50m^2$
Workshop	Equipment development office.	$50m^2$
Total area: $620m^2$		
Areas for employees, calculated as explained in 5.2.2		
An office area to accommodate the number of employees MCW is aimed to grow into.		
Kitchen and dining room for the staff.		
Gym and relaxation room for the employees.		
Separate bathrooms for men and women.		
One large meeting room.		
Two medium meeting rooms.		
Three small meeting rooms.		
At least one reception room.		
Total area: 20x25=500m^2		

5.3.5 Combination of all factors leading to actual space requirements

To come up with the final eight scenarios of warehouse size for storage of SKUs seen in 5.2.1, the results from 5.3.1 inhouse/externally & stock keeping units added/subtracted, 5.3.2 seasonality, peak to average & forecasting and 5.3.3 pallet & floor utilization are used. The warehouse will be dimensioned to meet the space requirements Mips' face in 2 years from the forecasting. The calculation is the same for every scenario, using different scenario-specific values. First, the total demand for pieces of LFLs and generic components for the year 2024 is converted into a number of pallets with the packaging information in table 5.1. With the yearly demand of pallets established, this is now converted into an actual average stored number of SKUs expressed in pallets. The number of SKUs to be added/subtracted are done in pallets/month. With the total simultaneously stored pallets in the warehouse known, finally, the needed warehouse area is calculated. It converts the pallets into an area and then uses both the pallet utilization and floor utilization to determine how much actual physical space is needed to store that amount. Then the last component, peak to average ratio, is multiplied by this figure in order to accommodate for the peaks in product flow within the warehouse. The equations can be seen in appendix C. The space requirement for the coming years is expressed in m^2 and the outcome of the eight scenarios can be seen in table 5.5.

Table 5.5: *Floor space for the different scenarios.*

Area	**10% annual growth from 12.5M 2021**				**15% annual growth from 12.5M 2021**			
B volume Inhouse	All new B inhouse		All B inhouse		All new B inhouse		All B inhouse	
Generic components stock inhouse, months	4	6	4	6	4	6	4	6
Needed warehouse area, m^2	*1173*	*1486*	*1339*	*1653*	*1427*	*1813*	*1619*	*2005*

5.3.6 Key takeaways

Mips have historically warehoused a big part of their products at their suppliers. Over time they will store a greater proportion in house, and by the year 2024, it is believed that around 60% will be distributed through their own warehouse. There are a few additional generic components that will be added or removed in the future. These will have a smaller logistical impact but are still accounted for. The components per LFL will increase and thus the percentage growth of components versus LFL will not be the same. Historically, Mips have had peaks in sold products in the later quarters of the year. The biggest peak was at 1,67 in relation to that year's total volume. The pallet utilization was calculated to be 70% in 2021, while the total figure is lower, consolidating small orders adjusts it towards 70%. From the number of pallets in 2021 and the current warehouse area, the floor utilization is 40%. Beyond the warehousing area, different other areas will be fitted in the warehouse taking up an additional $620m^2$. In the building, space for employees including for example office, kitchen, and bathrooms requires $20m^2$ for each one resulting in an additional $500m^2$. Eight scenarios make up the range of possible warehouse sizes needed based on projected sales, packaging information, pallet utilization, floor utilization, and peak to average. Peak to average is crucial since Mips have consistently experienced peaks above 50% of average.

5.4 Layout

5.4.1 Class division

The SKUs are hard to find for new employees because they don't have any dedicated locations. Considering that MCW will grow in employees it creates a need to have a more structured system which is highlighted by Mips. The SKUs will therefore be assigned to dedicated storage based on if they are LFLs or generic products. Within the LFL storage area, shared storage will be used since the SKUs often only stay for a short period of time in MCW and new LFLs regularly are introduced. The generic products will have dedicated storage since they always are kept in stock in MCW. Based on the theory it is common to implement class-based storage together with shared/dedicated storage. In MCW only the generic components will have class-based storage as the amount of LFLs in stock differs a lot. The classes are categorized into A, B, and C. The base is that A is the SKUs with pallets of a running total of 70%, B the following SKUs with pallets of a running total of 20%, and C is the last 10% but it is adjusted according to differences in demand. The data used is the summation of sales data for each generic component between 2020 to 2021 to get an overview over the most recent years. Since the product changes each year and the company grows, a new evaluation can be made continuously regarding the categorization of classes. The classification can be seen in table 5.6.

Table 5.6: *Classification of generic components.*

Storage classification of generic components	Running total of pallets	%age of generic components
A	71%	19%
B	71-90%	16%
C	90-100%	65%

The future demand must also be taken into consideration when designing the classes but as Mips strive to still store 50% of its generic components at suppliers that will not cause any change. The demand for generic components is forecasted in 5.3, capacity, but forecasting each class is not necessary. Instead, the storage area for the generic components will be the same but the classification inside it can fluctuate. However, the classification of the generic components needs to be evaluated regularly to have the right SKU in the right class. The classes can further be turned into FPA and reserve areas. From the theory, Adil et al., (2020) mentioned that the SKUs in the FPA should come from class A and some selected SKUs from class B. Class A consists of 12 SKUs and the monthly amount of pallets differs between 3 to 0.5. The four most popular SKUs in class B are determined to be in the FPA as they have a monthly demand of 0.4 to 0.3 pallets. The number of pallet positions in the FPA is therefore calculated by rounding up the monthly demand to full pallets of each SKU in the FPA and will consist of 20 pallet positions where the majority of the SKUs have 1 each but the top ones in class A have 3 or 2. The restocking of the FPA is calculated as presented in equation 1 in chapter 3.2.3. The equation gives 104 restocks per year. The rest of the SKUs in class B and all in class C will be in the reserve area.

5.4. 2 Layout shape

Both an I-shape or U-shape layout could be used in the warehouse since there will continue to be few trucks arriving and departing each day which will not lead to congestion. However, since the warehouse has a low activity and few SKUs Bartholdi & Hackman (2014) suggests a U-shape. To facilitate the U-shape layout the aisles will be located in relation to that in order not to cause congestion. Since Mips stores the majority of products on pallets and the flow of volume is low, few aisles are suitable.

5.4.3 Key takeaways

Mips should switch to dedicated storage of generic components in contrast to spontaneous placements as of now to facilitate easier understanding of the storage for new employees, which is important as the company grows. The LFLs will be assigned to a shared storage area because of the quick turnaround time and the frequent introduction of articles. The generic components will have static dedicated positions since they are always kept in the warehouse with large quantities of safety stock. They will further be class-based upon their share of sold volume in 70%, 20%, and remaining 10% brackets with the percentage of generic components being 19%, 16%, and 65% respectively. This needs to be evaluated annually. Class A and to some extent class B will be in a FPA while the remaining part of class B and all of class C will be in a reserve area.

I- and U-shapes are both functioning layouts because of low frequent shipment and arrivals but a U-shape is preferred because of that the warehouse has a low activity and few SKUs. Few aisles are preferred over many due to low flow of volume and accessibility is prioritized.

5.5 Equipment & automation- and information systems

The equipment in MCW is referring to storage and handling equipment as well as automation and information systems.

5.5.1 Storage & handling equipment

As mentioned in the theory, the advantages of racks are many, but also most suitable for warehouses that have a lot of different SKUs. Mips is currently using it for smaller volumes of LFLs and wants to continue to do that in the next warehouse as well. Usually, racks are referring to the storage of full pallets but in Mips' case, it is only for cartons that are handpicked. Mips does not want the storage of full pallets in racks as it would lower the efficiency in put-away and picking as well as create a need for larger aisles which in turn would reduce the space utilization in the warehouse. As of today, there are 50 single deep racks but it can be estimated that more racks will be needed in the next warehouse linear to the growth of products, 55 or 58 racks depending on 10% or 15% growth. The SKUs will continue to be picked by FIFO and single deep racks are therefore a suitable choice, it also means that each SKU has one or more positions depending on how often they are picked. These types of racks can store approximately 225 cartons more than floor storage in the same area, for calculations see appendix C. Racks are therefore seen to be more space-efficient. The SKUs in the racks will hold LFLs of small quantities as today and therefore not be situated in a position that would suit FPA or reserve area better.

MCW has used maximum yearly demand of pallets for 2024 of 4000 pallets which is around 2 pallets per hour but can be seen to have a quite high number of SKUs as new LFLs constantly are being introduced. Mips can be placed in Baker & Naish's (2004) figure as can be seen in figure 5.7. According to the theory of the figure, motorized forklifts to put-away pallets are needed but no further automation. The amount of handling equipment needed in the new warehouse is following; 3 wagons, 1 forklift, 3 electric hand pallet jacks, and 3 manual hand pallet jacks. This is based on the current warehouse with an addition of 2 electric hand pallet jacks after a conversation with Mips.

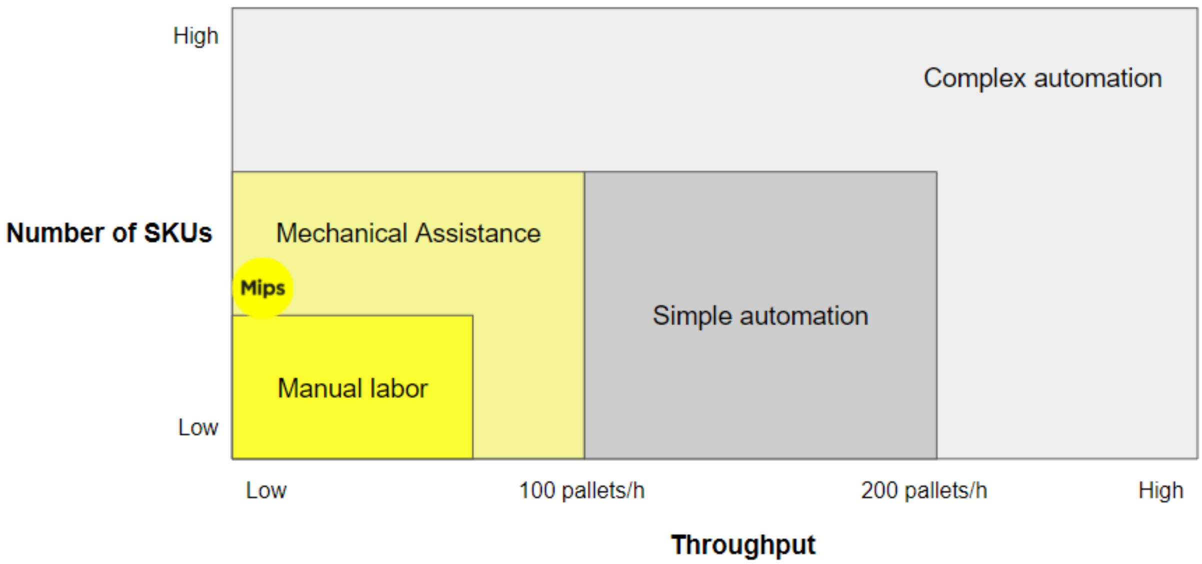


Figure 5.7: *Mips' position in Baker & Naish's model, 2004.*

5.5.2 Automation & information systems

Mips wants to have scanners in the new warehouse to digitize its warehouse and easier connect the SKUs' physical positions with data. It will help new employees to better understand the placement of SKUs and avoid errors, which is important for the company's growth of employees and the strategy of having a very high service level. As scanners reduce operational costs while increasing the possibility to store a wide range of products, it is very suitable for Mips. To use scanners a WMS must also be implemented in the current ERP system. As mentioned in the theory a WMS can help locations be clear and well defined and reduce errors related to manual tasks as well as provide higher accuracy in stock level reporting, which are all important aspects to Mips. Another implication for scanners is that could lead to better pallet utilization by storing different SKUs on the same pallet but being able to have it in a structured way by connecting the positions with the WMS.

5.5.3 Key takeaways

Mips will continue to pick some LFLs from boxes in single deep racks. This is because full pallets in the racks would not be suitable because of poor efficiency in put-away and picking and it would also need more space, reducing the floor utilization. Mips have relatively low throughput and a moderate number of SKUs which makes the MCW appropriate for manual labor, and 3 wagons, 1 forklift, 3 electric hand pallet jacks, and 3 manual hand pallet jacks will be used as equipment. Scanners will be implemented in the warehouse to reduce administrative paperwork and help organize the growing operations. This will need to be accompanied by an implemented WMS to the current ERP system. This will also increase accuracy and traceability within the warehouse and for example, make sure that the designation of locations is done.

5.6 Proposed solution

5.6.1 Consideration to warehouse purpose

It is important to address the fact that Mips' most important performance measure is that they have a high service level and their strategy moving forward is highly oriented towards keeping this promise. This means that it is critical that they can serve all the customers that they acquire since the growth of their company is a higher priority than saving money. For this reason, configuring the warehouse in such a way that it handles peaks and even larger growth than what is reasonably expected is relevant. However, it does not mean that disruptions will not occur in the operations, that is inevitable. But it is important that the warehouse capacity is considered in relation to their growth targets which implies that they must be ready to handle strong growth when they introduce new products to customers. Having to switch warehouses sooner creates a disruption in the growth process and is a hassle overall. With regards to Mips's history of having switched warehouses every other year, it is further believed that pushing for that extra space is justified. The scenarios from the frameworks ultimately result in different suggestions for needed warehouse area, see Table 5.5: Floor space for the different scenarios. After this point, the suggestions become the result of a review in likeliness of Mips. This is not quantified but rather chosen on overview of the total of suggestions. From discussion with Mips, $1486m^2$ is chosen to be the best alternative of the most probable outcome as well as risks of higher volumes.

5.6.2 The foundation of analysis

The framework is built on previous well established frameworks for network design and fit for a fast growing company mainly with the implementation of scenarios to accommodate for the uncertainties of a fast growing company as well as designed for good practical use. This is because forecasting in fast growing companies is difficult (Carson et al., 2013). With the use of this qualified framework a suggestion has been made. The analysis is made on the basis of company data gathered from their ERP system. The system tracks many different aspects of the organization, from sales to warehouse inventory data. The data that has been used for calculations of the parameters, such as pallet utilization, has been verified through comparison with sales data, in an attempt to verify that different sources of information suggest similar behavior in the operations. More specifically, sales data have been compared to inventory movement data to verify that the flow of product corresponds to what it did. The packaging information was put together by the MCW manager who works with the packages on a daily basis. He must be considered knowledgeable about the dimensions of packages in the warehouse. With thorough consideration of the scenarios, the majority of parameters calculated and confirmed to be accurate with employees, the suggestion of warehouse area should be considered a highly qualified estimation of needed warehouse area for Mips.

5.6.3 Sizes of areas and the chosen layout

The size of other areas are a result of the growth in employees, higher volumes and based on the current situated rooms in the warehouse that are needed for the operations. Bathrooms and general areas are directly proportional to the amount of employees in the workplace while for example LFL sample rooms are in proportion to product volume. The layout of the storing area is suggested to be U-shape because of low frequent shipment and arrivals, a low activity and few SKUs. Also, there is no need for separate incoming and outgoing products which would promote an I-shape instead. This is based on the thoroughly reviewed and recited article of Bartholdi & Hackman (2014) which solidifies its answer in this situation. With the help of Koster et al. (2007), the solution has been able to identify that tactical decisions have more impact on this warehouse than operational decisions, which is why tactical decisions such as the layout is emphasized over order picking routing. This keeps the focus during the implementation of the framework at decisions that are relevant for the warehouse.

5.6.4 Automation level

Using Baker & Naish's (2004) model, figure 5.7, the choice of manual equipment over automation is anchored in theory. The use of racks to store the LFLs in cartons instead of pallets will increase the efficiency in put away and picking, ultimately enhancing the space utilization that would otherwise be lowered with the use of pallets in the racks. Considering their current setup, three wagons, one forklift, three electric hand pallet jacks and three manual hand pallet jacks will suffice moving forward. Mips current way of using unofficial picking locations that the employees learn is a problem that will be solved with the implementation of a WMS. This is proposed partly from Harb et al. (2016) that discovered that locations became clear and well defined after implementing a WMS. Anđelković and Radosavljević (2018) agree on this point. And even more generally, companies that choose not to implement WMS in their warehouse are at a competitive disadvantage. Scanner will be added in conjunction with the WMS since both the employees and theory supports it because it gives near perfect accuracy and it enables the workers to work more fluently without the administrative work of paper (Faber, 2002; Baruffaldi, 2019).

RO3 is the proposed solution, and the findings from chapter 5 lead us to this. In table 5.7 the decisions taken from the developed framework can be seen, which is the proposed DC design of the new warehouse for Mips.

Table 5.7: *Area and decision.*

Area	Decision
Size of warehouse	1486 + 620 = ~2100m^2
Size of other areas	500 m^2

Layout	U-shape. Shared storage for LFLs, dedicated for generic components. Also class-based storage with FPA and reserve area for generic components.
Storage handling equipment	55 racks for storage of LFLs in cartons. 3 wagons, 1 forklift, 3 electric hand pallet jacks and 3 manual hand pallet jacks.
Automation and information systems	The current ERP system but with the addition of having a WMS to help in the daily activities and work with scanners.

5.6.5 Key takeaways

The new DC will have storage of $1486m^2$, which is the scenario for 10% growth, all new B will be inhouse and 6 months of components safety stock. Involved in the decision-making is the strategy at Mips which dictates that they benefit more from hedging with a larger warehouse to accommodate for a bigger than expected outcome than it is to undercut size and fail in operations. Since they are categorized to be in the growth phase for a few more years at least, in the business life cycle, it is evident that a larger warehouse is needed considering that they have switched every other year in history as well. Other areas in the warehouse as sample room etc. will be $620m^2$ and other areas for employees will be $500m^2$. Mips will also have a U-shape layout, shared storage for LFLs and dedicated for generic components. The generic components will also have a FPA with the most picked SKUs and a reserve area. There will be 55 racks in the new warehouse for storage of LFLs in cartons, 3 wagons, 1 forklift, 3 electric hand pallet jacks and 3 manual hand pallet jacks. The current ERP system will be extended with a WMS to help in the daily activities and work with scanners.

6. Conclusion

Here the thesis will be concluded by summarizing the key findings and answering the research objectives. Contributions to practice as well as theory will be highlighted, as well as suggestions for future research. The choices made throughout the journey will here be discussed. Also the limitations of the study, the credibility of data, sources, and the persons interviewed. Thoughts regarding the new conceptual framework and the final recommendation will also be presented.

6.1 Answer to the research objectives

The two research objectives in this thesis were:

RO1: Formulate a new conceptual framework to match the capacity requirements of a fast-growing company.

With the use of the information from the literature review in chapter 3, two interesting findings were identified. First, the most well-cited and used frameworks in literature are over a decade old (Hassan, 2002; Baker & Canessa, 2009; Mantela et al., 2002), and may thus not be developed with the fast pace of today's environment in mind. Secondly, the identified frameworks all build on utilizing existing data for forecasting future capacity needs and not on possible scenarios. Three criteria for a design framework for a fast-growing company were therefore developed together with Mips and this in mind as well as the aim of the study regarding design.

RO2: Propose a DC design for Mips by implementing the developed conceptual framework.

The new developed conceptual framework was applied at the case company Mips with collected data from interviews and archival records. This resulted in a proposed DC design regarding size of areas, layout, and equipment & automation.

RO1 responds to chapter 4, with the result of the framework in 4.3 which was created by the criteria and literature review. In the framework, the five steps can be seen to have different implications for the design and capacity aspects. Step 1 is aimed to understand the current situation and the data that should be used in further calculations, as well as the pros and cons of the current layout. Step 2 is aimed to help forecast demand and future products that will have implications for the capacity of the warehouse and is a way of forecasting for a fast-growing company. Step 3 sets the capacity requirements for the future growth of the company. Step 4 is crucial in the design process, as well as step 5, which also is useful, especially as it is important to not lack behind digitalization. Step 6 is the proposed solution where one of the scenarios is decided and a summary of the decisions taken throughout the other steps. Step 6 therefore responds to RO2 as it is the proposed solution of a DC design for the case company Mips. The new conceptual framework aims to cover everything that the thesis aims for but make it general for companies other than Mips to use it as well.

With the proposed solution presented in 5.6, Mips has now begun searching for a suitable DC they can move to in a couple of months. Mips have not had any theoretical background to their previous decisions regarding the choice of DC. This framework can therefore be used again when it is time to find the next warehouse after two years.

6.2 Discussion of results and thesis process

The utilization factors in the calculation of warehouse size are not as accurate as other factors affecting the result. The robustness of the final result is, therefore, tested by changing these values. In table 6.1 it is possible to see the chosen values and values 10 percentage points lower and higher. As can be seen, the range becomes wide and the takeaway is that it is important to keep that in mind when looking at the result. Especially as only one value is picked from the scenarios instead of a range, which creates even more uncertainty in the result of the warehouse space.

Table 6.1: *Robustness of calculation of warehouse space.*

	Low	**Chosen**	**High**
Pallet utilization	60	70	80
Floor utilization	30	40	50
m^2	**1800 to 3100**	**1200 to 2000**	**800 to 1400**

Figure 6.1: *Graphical representation of robustness of the calculation of warehouse space.*

The literature used in the frame of reference can be seen to be trustworthy as almost all of the sources are well-cited scholarly literature. Some of the sources are from industry-specific websites but can be seen to be reliable as the writers are experts within the field. Some of the articles are quite old, but they have been cited so many times in new literature and are therefore used as the primary source. When important topics are covered, attempts have been made to use many sources to strengthen the credibility. The newest prior research framework is from 2009, which can be argued to be outdated. However, the three of the frameworks were picked because they were the ones found in most articles. Regarding DC design, what has changed the most is the automation and information systems, which are included in the developed framework but not a very big part of the analysis.

To cover the spectrum of possible scenarios as well as covering the different parameters that affect the solution is an attempt to create a foundation for decision-making now and in the future. The more nuanced a solution or model gets, the decision can be solidified to a comfortable level of basis. Mips expresses that the thesis has contributed to a result that will be taken into consideration but more so that they have been given a framework for future use in determining the needed warehouse area. Even though part of the objective was that the results of the thesis should be transferable, the framework also became reusable for Mips regarding future warehouses. The steps should be considered as decision criteria and the more detailed and accurate they can be, the better the result gets. The steps show how one could examine the realm of supposedly suitable alternatives in every unique case and that judgment can be used after that in moving forward through the decision-making process. The framework does not specifically attest to how to conduct every step. Instead, the framework is used in conjunction with theory from the frame of reference along with validation with Mips. What should be said about choosing a framework is finding one that facilitates a methodological approach where the involved steps cover all relevant aspects. Then a practitioner of the framework can remove some and focus on the ones that are perceived to make the most impact for that specific case of configuration.

Interestingly enough, the framework itself was built early on, and the result of warehouse size presented in the half-time presentation was not far away from the final recommendation. Even though the framework went through some modifications, the biggest difference from the halftime recommendation to the final recommendation was the change of values in the parameters. At first, many of the values were based solely on interviews with employees. They had not themselves investigated and calculated these parameters but made guesses based on their experience within the operations. When they were analyzed based on archival records, they differed from the perceived values that we in turn, could adjust and granulate the recommendation. The values were both over- and underestimated, which made the final result similar, though not exactly alike, to the first draft. This was an interesting experience because it showed the concept of being wrong and then less wrong. Where the aim is to granulate and solidify to a certain point where the answer can be perceived as acceptably wrong, which was the case with the warehouse size.

In chapter 3.3 there were four steps that older frameworks and the most recent agree on regarding warehouse design; Frameworks are hard because the design process is complex, the framework uses step-by-step approaches, the steps are interrelated, and the design process needs to involve reiteration to some extent, the “optimum” solution cannot be found due to the high number of possibilities and variations from every step of the design process. This applies to the almost full extent to the new conceptual framework as well. During the work with the thesis, the researchers found exactly how hard it is with frameworks. It is a process that requires verification and discussion, which takes time and data. The new framework also has a step-by-step approach from which the steps are interrelated. Even if the design process has no criteria that it needs to be iterated, the researchers used an iterative process in the case of Mips. As mentioned, it also became clear during the process that there was no optimum solution. Instead, the framework is a tool to develop the design.

As mentioned in chapter 3.3, Geuken & Jäger (2015) developed a framework for fast-growing companies. Similarities to this framework is the first step of defining the warehouse objective, which is to be compared with our own step of current setup. Both Geuken & Jäger's framework (2015) and the developed framework in this report involve the initiation of defining the warehouse purpose to guide the forward process. The later steps of analyzing equipment and plan space requirements are similar as well. The big differences between the two frameworks are mainly the steps of scenarios emphasized in our framework, which is our strategy of dealing with uncertainty of a fast growing-company. The second big difference is that they generate numerous layouts and identify the preferred solution from the many, whereas our framework suggests one solution from the many steps. From the scenario breakdown an identified solution is chosen, in terms of space requirements, that is used as the basis of later decisions such as equipment and other areas. The reason for developing our own framework was the lack of widespread knowledge specifically for fast-growing companies in the area. Because of that we wanted to create our own framework to broaden the area and not only extend on top of other frameworks such as Geuken & Jägers (2015).

6.3 Contribution to practice and theory

The thesis has been an attempt to propose a DC design suitable for Mips' current situation and two years ahead. The contribution to practice has mainly been for Mips to use the result presented in 5.6 when searching for a new warehouse or the new developed conceptual framework further in the process of finding the new warehouse or when it is time again after two years. Even if there exist frameworks for the design of warehouses, there are not many dedicated to fast-growing companies specifically. With inspiration from Hassan (2002), Baker & Canessa (2009), and Mantela et al. (2002), along with multiple authors on warehousing, a framework for DC design has been developed. The biggest distinction from former frameworks is the involvement of a scenario analysis and compact regarding the amount of steps, which also are the biggest contributions to theory. The scenarios are used to mitigate the uncertainties related to a fast-growing company. Even if the scenarios are particular, hopefully, other practitioners and researchers can find them useful as inspiration or guidance in picking their own scenarios. The compactness of the conceptual framework is an attempt for it to be easy for practitioners of it to understand, why it has few steps. The previous frameworks often include many steps, which are similar to each other and can be confusing for someone not familiar with all concepts. With inspiration from the previous steps many of them are therefore grouped together to include more aspects but easier to understand.

6.4 Limitations & future research

The limited time frame of 20 weeks led to some parameters not being as researched as others. The determination of automation solutions could be investigated deeper regarding what is suitable for a fast-growing company and a more break-down analysis of types of WMS. In this thesis, decisions were made to a large extent on the employees' opinions. Even if the employees at Mips are very familiar with the case, it would be further generalizable to have literature and theory supporting decisions. Emphasis is placed on values that greatly influence the results, and it is deemed critical that these figures are confirmed numerically and by the knowledge of involved parties. Parts of the calculations that have fewer implications have been analyzed when time constraints made it possible and some were left only to be established by people's opinion. In summary, the framework and its main steps can be used by other researchers. However, it is not as easy to transfer the content within the steps. As a single case study, there are also limitations as only one case, Mips, is being studied. The framework is produced with the aim of being used in fast-growing companies. However, only one single fast-growing company is explored in the thesis and is the basis of the forthcoming of our framework. Other fast-growing companies could impose other suggestions for suitable components of such a framework. It would be interesting to apply this framework to other fast-growing companies and review the people's opinions of its suitability as well as its performance in hindsight. Of course, the framework does not depict precisely how the steps should be carried out. For example, forecasting of demand or layout decisions are both areas where practitioners can enforce their own strategies for calculation and choice. The framework is a more holistic approach to proceeding with the project of designing a warehouse. Another limitation was that Mips does not have that many employees, so the range of suitable interviewees was not that wide. However, the number of interviews can still be seen to be enough, primarily since correspondence was held and the interviewees had a lot of knowledge. Further research can base more decisions in the framework on archival records/theory rather than people's opinions. Views and perceptions of employees at Mips are used mainly to verify results which is ideal from a confirmability standpoint. However, parts of the solution are directly taken from the perception of Mips' employees, such as the turnover time of LFLs in the warehouse. The authors have not been successful in calculating these numbers themselves and, as a result, have been forced to rely on warehouse managers' perceptions. This is, of course, not ideal from a confirmability standpoint and remains a relative uncertainty in the analysis. Another researcher will not be presented with the same resources and as such can not dictate what information they should be given. It worked great when the knowledgeable employees at Mips could both answer questions that were prepared, but also make recommendations as well as add nuances to the analysis. This does not mean that they dictated the process, but it showcased aspects that had not been taken into account otherwise. The research was fortunate to take place in such a dynamic and responsive environment, but it also means that other researchers may lack the dependability when consulting with it and the result from the framework can be hard to imitate.

The framework has been developed with the intention of using it at Mips, to increase the generality and validity, it should be applied in more cases. To improve its validity, it could be applied to other companies as well and be adjusted based on that. Since the conceptual framework also is mainly developed from the most common steps of previous frameworks and opinions from Mips' employees, it could be further developed by an outside party to come with an open mind and new insights. In a similar way as Baker & Canessa's (2009) framework is developed from six previous frameworks. The scenarios that are included within the framework are suggested by Mips' employees. This is a benefit in the sense that they are most knowledgeable in their own operations and know through experience what scenarios could be possible. At the same time, they may not have the most objective perception of the risks to their operations and could be focused on complex problems when there are possibly bigger uncertainties tied to the operations that are overseen in this case. The scenarios also create a range of the size of the warehouse. To get a more precise result, it would be an option to research if there is a better way to deal with uncertainties. A sensitivity- or risk analysis could be performed as an alternative.

References

Aase, G., and Petersen, C., (2004). "A comparison of picking, storage, and routing policies in manual order picking", *International Journal Of Production Economics, 92(1), 11-19. doi: 10.1016/j.ijpe.2003.09.006*

Aastrup, J., and Halldórsson, Á., (2003). "Quality criteria for qualitative inquiries in logistics", *European Journal of Operational Research, 144(2), 321–332.* *https://doi.org/10.1016/S0377-2217(02)00397-1*

Adil, G., Singbal, V., and Venkitasubramony, R., (2020). "Case–Forward-Reserve Storage Design: A Case of Carriage Repair Workshop", *Indian Railways. INFORMS Transactions on Education. 21. 10.1287/ited.2019.0228cs.*

Agarwal, P., Kumar, A., Kumar, T., Vanaja, R. and Yadav, A., (2020). "Lifo in green supply chain inventory model of auto-components industry with warehouses using differential evolution", *Advances in Mathematics: Scientific Journal 9.*

Anđelković, A. and Radosavljević, M., (2018). "Improving order-picking process through implementation of warehouse management system", *Strategic Management, Vol. 23(2), pp. 3-10.*

Azadeh, K., De Koster, R., and Roy, D. (2019). "Robotized and Automated Warehouse Systems: Review and Recent Developments", *Transportation Science.*

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

Baker, P., and Naish, S., (2004). "Materials Handling Fulfilling The Promises", *Logistics & Transport Focus, 6(1).*

Bardi, EJ., Coyle, JJ., Gibson, BJ., and Novak, RA., (2011). "Management of Transportation", *Vol 7. Canada: South-Western Cengage Learning.*

Bartholdi, J., and Hackman, S., (2008). "Allocating space in a forward pick area of a distribution center for small parts", *School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0205, USA.*

Bartholdi, J., and Hackman, S., (2014). "Warehouse & Distribution Science", *Release 0.96, Supply Chain and Logistics Institute, Atlanta.*

Bartholdi, J., Hackman, S., and John J., (2019). “Warehouse & Distribution Science”, *0.98.1 ed., The Supply Chain & Logistics Institute H. Milton Stewart School of Industrial and Systems Engineering Georgia Institute of Technology.*

Baruffaldi, G., Accorsi, R. and Manzini, R. (2019). “Warehouse management system customization and information availability in 3pl companies”, *Industrial Management & Data Systems, Vol. 119(2), pp. 251-273.*

Bernot, M., Caselles, V., and Morel J, M., (2009). “Optimal Transportation Networks, Modes and Theory”, *Berlin: Springer-Verlag Berlin Heidelberg.*

Bookbinder, J., and Higginson, J., (2005). “Distribution Centers in Supply Chain Operations”, *Logistics Systems: Design and Optimization (pp.67-91).*

Bozer, YA., Tanchoco, JMA., Tompkins, JA., and White, JA., (2010). “Facilities planning”, *John Wiley & Sons.*

Bustamante, F., Dekhne, A., Herrmann, J., and Singh, V., (2020). “Improving warehouse operation - digitally”, *McKinsey & Company.* *https://www.mckinsey.com/business-functions/operations/our-insights/improving-warehouse-operations-digitally (2022-04-27)*

Carson, S., Karniouchina, E., Ketchen, D., and Short, J., (2013). “Extending the firm vs. industry debate: Does industry life cycle stage matter?”, *Strategic Management Journal, 34(8), pp. 1010-1018.*

Chambers, J., Mullick, S., and Smith, D., (1971). “How to choose the right forecasting technique”, *Harvard Business Review, Magazine July.*

Chen, H. Interview by Jonasson, E and Olsson. L. (2022-02-14)

Chu, L., and Wright, S., (2022). “23 Warehouse Pros Reveal the Biggest Mistakes Companies Make When Designing a Warehouse Layout (and How to Avoid Them)”, *Camcode* *https://www.camcode.com/blog/warehouse-layout-and-design/* (2022-04-27)

Cox, W.E. (1967). “Product Life Cycles as Marketing Models”, *Journal of Business, 40, 375-384. https://doi.org/10.1086/295003*

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

https://doi.org/10.1007/s12159-014-0120-1.

De Koster, R., Faber, N., and Smidts, A., (2013).“Organizing warehouse management”, *International Journal of Operations and Production Management, Vol. 33 No. 9, pp. 1230–1256.*

De Koster, R., Johnson, AL., and Roy, D., (2017). “Warehouse design and management”, *International Journal of Production Research, 55(21), pp. 6327–6330. doi: 10.1080/00207543.2017.1371856.*

De Koster, R., Le-Duc René, T., and Roodbergen, KJ., (2007). “Design and Control of Warehouse Order Picking: A Literature Review.” *European Journal of Operational Research 182 (2): 481–501.*

Dudovskiy, J., (2022). “Formulating Research Aims and Objectives” , *https://research-methodology.net/research-methodology/research-aims-and-objectives/*

Eisenhardt, KM., (1989). “Building Theories from Case Study Research”, *The Academy of Management Review, 14(4), 532–550. https://doi.org/10.2307/258557*

Eurostat-OECD, (2007). “Eurostat-OECD Manual on Business Demography Statistics”, *Office for Official Publications of the European Communities, Luxembourg.*

Faber, N., de Koster, R. and van de Velde, S. (2002). “Linking warehouse complexity to warehouse planning and control structure”, *International Journal of Physical Distribution & Logistics Management, Vol. 32(5), pp. 381-395.*

Fei, Y., Lou, Z., and Yin Y., (2009). “Risk Analysis and Measurement in Warehouse Financing”, *IEEE International Conference on e-Business Engineering.*

Fisher, ML., (1997). “What is the Right Supply Chain for your Product?”, *Harvard Business Review, 75(2), pp. 105-116.*

Frazelle, E., (2002). “World-class warehousing and material handling”, *New York: McGraw-Hill.*

Frohlich, M., Tsikriktsis, N., and Voss, C., (2002). “Case research in operations management”, *International Journal of Operations & Production Management, 22(2), 195–219. https://doi.org/10.1108/01443570210414329*

Gademann N., Pochet, Y., Sharp G., and Van den Berg, J., (1998). “Forward-reserve allocation in a warehouse with unit-load replenishment”, *European journal of operations research 111 (1998) 98--l 13.*

Geuken, F., Jäger, L. (2015). “Developing a Warehouse Layout Design Framework for Fast Growing Companies”, *Master's Thesis, Faculty of Engineering, Lund Univeristy*. https://lup.lub.lu.se/student-papers/search/publication/7370739

Glaskowsky, N., Heskett, J., and Ivie R. (1973). “Business Logistics; Physical Distribution and Materials Management”, *Ronald Press Company.*

Gu, J., Goetschalckx, M. and McGinnis, L. F. (2010). “Research on warehouse design and performance evaluation: A comprehensive review”, *European Journal of Operational Research, Vol. 203 No. 3, pp. 539–549.*

Harb, A., Kassem, A., Chartouni, M. and Chaaya, L., (2016). “Effects of Warehouse Management and engineering system on cost reduction and operations improvement”, *2016 Sixth International Conference on Digital Information Processing and Communications.*

Hassan, M., (2002). “A framework for the design of warehouse layout”, *Facilities, 20(13/14), p. 432-440.*

Holme, IM., and Solvang, BK., (1997). “Forskningsmetodik om kvalitativa och kvantitativa metoder”, *2nd ed. Lund: Studentlitteratur.*

Holzapfel A., Hübner, A., and Kuhn H. (2016). “Distribution systems in omni-channel retailing”, *BuR - Business Research.*

Huberman, AM., and Miles, MB., (1994). “Qualitative data analysis: An expanded sourcebook (2nd ed)”, *Sage Publications.*

Höst, M., Regnell, B., and Runeson, P. (2006). “Att genomföra examensarbete”, *Lund, SE: Studentlitteratur AB.*

Indeed Editorial Team, (2021). “Research Objectives: Definition and How To Define Them”, *Indeed* https://www.indeed.com/career-advice/career-development/research-objectives (2022-03-23)

Ingelund, N. Interview by Jonasson, E and Olsson. L. (2022-02-08)

Isaksson, S. Interview by Jonasson, E and Olsson. L. (2022-02-14)

Jahnukainen, J., and Lahti, M., (1999). “Efficient purchasing in make-to-order supply chains”, *International Journal of Production Economics, Volume 59, Issues 1–3.*

Kamoshida R., and Kazama Y., (2017). “Acquisition of Automated Guided Vehicle Route Planning Policy Using Deep Reinforcement Learning”, *6th IEEE International Conference on Advanced Logistics and Transport.*

Kembro, J., and Norrman, A., (2019). ”Effektiv materialhantering och lagerverksamhet för ökad konkurrenskraft i multi- och omnikanaler”, *Handelsrådet, Forskningsrapport 2019:01.* (a)

Kembro, J., and Norrman, A., (2019). “Exploring trends, implications and challenges for logistics information systems in omni-channels : Swedish retailers’ perception”, *International Journal of Retail and Distribution Management 47(4). P.384-411.* (b)

Kembro, J., and Norrman, A., (2021). “Which future path to pick? A contingency approach to omnichannel warehouse configuration”, *International Journal of Physical Distribution & Logistics Management, ISSN: 0960-0035.*

Kong, C., and Masel, D., (2008). “Methods for Design and Management of a Fast-Pick Area in a Warehouse”, *Department of Industrial and Systems Engineering Ohio University, Athens, Ohio 45701, USA.*

Lee, H., (2002). “Aligning Supply Chain Strategies with Product Uncertainties”, *California Management Review, 44(3), pp. 105-119.*

Leedy, P., and Ormrod, J., (2001). “Practical research: Planning and design (7th ed.)”, *Upper Saddle River, NJ: Merrill Prentice Hall. Thousand Oaks: SAGE Publications.*

Leonard-Barton, D., (1990). “A dual methodology for case studies: Synergistic use of a longitudinal single site with replicated multiple sites”, *Organization Science, 1*(3)*, 248–266.*

Mantela, RJ., Reuter B., Rouwenhorst, B., Stockrahm, V., Van Houtum, GJ., and Zijmc, WHM., (2000). “Warehouse design and control: Framework and literature review”, *European Journal of Operational Research, Vol. 122 No. 3, pp. 515–533.*

McGinnis, LF., Murrenhoff, A., and Sprock, T., (2017). “A hierarchical approach to warehouse design”, *International Journal of Production Research, 55(21), pp. 6331–6343. doi: 10.1080/00207543.2016.1241447.*

Meredith, J., (1998). “Building operations management theory through case and field research”, *Journal of Operations Management, 16(4), 441–454. https://doi.org/10.1016/S0272-6963(98)00023-0.*

Opsdog, “Peak Warehouse Space Utilization” *Opsdog* https://opsdog.com/products/peak-warehouse-capacity-used (2022-05-10).

Oxley, J., (1994). “Avoiding inferior design”, *Storage Handling and Distribution 38 (2), 28–30*.

Payne, T., (2019). “How to Calculate Warehouse Space and Storage Capacity”. *T.P. Supply CO, Inc.* https://www.tpsupplyco.com/how-to-calculate-warehouse-space/ (2022-05-10)

Ramdasi, S., and Shinde, D., (2021). “Effect of FIFO Strategy Implementation on Warehouse Inventory Management in The Furniture Manufacturing Industry”, *International Journal of Engineering Research & Technology (IJERT).*

Roodbergen, KJ., Taylor Jr, GD., and Vis, IF., (2014).”Simultaneous determination of warehouse layout and control policies”, *International Journal of Production Research, (ahead-of-print), pp. 1-21.*

Rowley, J., and Slack, F., (2004). “Conducting a literature review”, *Management Research News.*

Saghir, M. (2004). “The Concept of Packaging Logistics”, *Second World Conference on POM and 15th Annual POM Conference.*

SAP “What is a WMS (warehouse management system)?”, *SAP.* https://www.sap.com/france/insights/what-is-a-wms-warehouse-management-system.html (2022-03-23)

Theodore Levitt (1965). “Exploit the Product Life Cycle”, *Harvard Business Review*.

Van den Berg, J., and Zijm, W., (1999). “Models for warehouse management: Classification and examples”, *International Journal Of Production Economics, 59(1), pp. 519-528.*

Wang, H., Chen, S. and Xie, Y. (2010). “An RFID-based digital warehouse management system in the tobacco industry: a case study”, *International Journal of Production Research, Vol. 48(9), pp. 2513-2548.*

Yin, RK., (2014). “Case study research: Design and methods (5th ed.)”, *Thousand Oaks, California, US: SAGE Publications, Inc.*

Appendix A - Interview questions for Supply Chain Manager

Begin by telling who the researchers are, what we are doing, the purpose of the interview and how long it will take (~1h).

General questions

1. Tell us about yourself?
2. What role do you have?
    a. What kind of responsibilities?
    b. Daily tasks?
    c. Long-term tasks?
3. How long have you been employed at Mips?

Network & product characteristics

Output: *Understanding how the corporate strategy affects the network and the warehouse in question. Network map of the material flow to and from the warehouse. Warehouse concept table. Product characteristics identification.*

1. How does the corporate strategy affect the warehouse?
2. What is the warehouse's key purpose?
    a. What type of DC is it?

Type of DC	Description
Pickup and delivery	Serves local areas. Pickup and delivery activities to customers/suppliers on a daily basis.
Cross dock/consolidation	High speed goods flow, goods are not stored. Consolidation of smaller orders or orders from different suppliers.
Break-bulk	Consolidation to or separation of large units before shipping to customers.
Relay	No goods handling, only change of driver.
Warehouse	Used to meet shifting demands by keeping safety stock.
Transfer	Freight shifts from one vehicle to another.

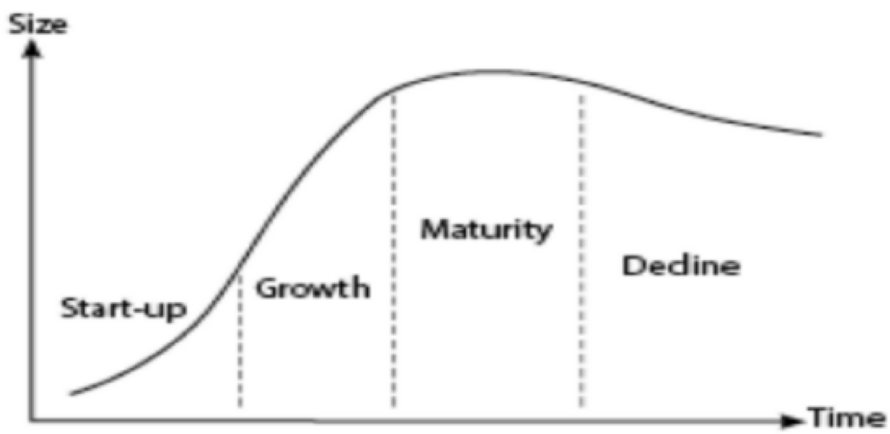
    b. Do you use KPIs or other metrics in the warehouse?
        i. In that case, which and why?
3. What are the new warehouse's design criteria, in the shape of performance measures, and how are they prioritized?
    a. Besides bigger volumes, what is different from the current?
    b. What are the requirements on the warehouse for the products?
    c. Do you have any restrictions to follow? Work-related, safety, etc.
4. Are there variations in storage handling units? Different types of pallets etc.

5. What is the type and dimension of the unit load?
6. Do you perform any value-adding activities in the warehouse?
7. What is the lead time for delivery of the current warehouse?
8. What is the average service level of the current warehouse?
9. How are the SKUs delivered? How often, by which vehicle, from where etc.
10. How are the SKUs characterized? Size, amount, weight, value, fragility, stackability, etc.
    a. Do they vary much in packaging or other requirements?

Demand

Outputs: *Demand profile for the time frame considered. Scenarios to use as sensitivity analysis.*

1. In what stage of the product life cycle are Mips's products situated?

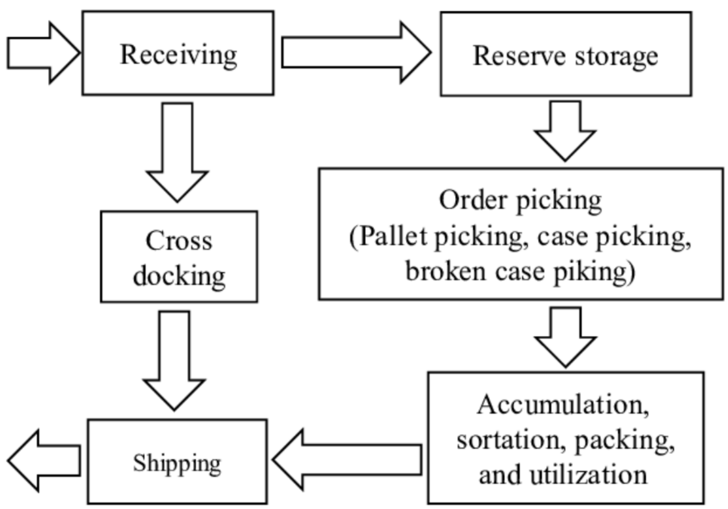


2. What is the demand for different SKUs?
    a. Is there any seasonality?
    b. How much safety stock do you have?
3. At peak demand, how do you deal with labor capacity?
4. How often are new products introduced, and how often are products phased out?
    a. For how long do the different SKUs stay in the warehouse?
5. How much is stored at other places than in the MCW, and where?
    a. What's the cost of it?
    b. What is the reasoning behind it?
6. How has the growth been over the last five years in both the number and amount of SKUs and warehouse size?
    a. What is the expected growth for the coming years?
    b. What is that dependent on?
        i. Do you have any other scenarios?
7. What in the demand profile is likely to change operations in the warehouse?
8. What are the current costs of the warehouse?
    a. What accounts for the largest spending?

Storage handling & departments

Outputs: *Ancillary activities. Process map over the future state of the material handling process. Understanding the proportion of orders and units handled is of each storage handling unit. Identification of the need for departments regarding storage handling units*

1. How does the current warehouse layout look, and what are its benefits and flaws?
    a. Is it purposefully planned?
2. Could you explain the operations in the warehouse and their flow? Please do it for each department.



    a. Where are the entrances and exits situated for all departments?
    b. Where is the receiving and shipping dock located?
    c. How should the material flow in the warehouse be designed to be aligned with the corporate strategy?
3. What are the departments, and how are they related to the operations?
    a. How many people work in each department?
    b. What are the space needs of the different departments?
4. Which ancillary operation activities should be performed in the warehouse?
    a. Where should ancillary operations be placed to increase efficiency and facilitate workflow?
5. Where is quality control made? At suppliers, MCW, etc.
6. What is the storage method?
    a. Do you have a dedicated, shared space or a mix of both?
7. Do you have the SKUs assigned to classes or zones?
    a. How are they assigned in that case?
8. How are the reserve and picking areas divided?

   a. How are the deviations of them related to other aspects? Demand, characteristics of products, potential classification, the type of unit loads, etc.
9. How is the picking process?
   a. How is the picklist generated?
   b. What is the average picking efficiency?
   c. What is the average picking accuracy?
   d. Do you use batching?
10. How are the aisles? Amount, location, orientation, dimensions, etc.

Equipment & automation level

Outputs: *Identified automation level. Decision table of equipment setup. Space requirements for equipment set up and storage process.*

1. What types of racks are there, and what is their dimension?
   a. What equipment is complementary to the rack system?
   b. What limitations are set on the rack system by the product requirements and equipment used?
2. What is the handling equipment?
   a. Where is the handling equipment stored?
3. How much of the labor is done manually, and how much with trucks?
   a. What types of trucks is it?
4. What automatic solutions do you have?
   a. Why do you have them?
   b. Where do you have them, in which departments?
   c. Are there any other solutions you might find useful?
5. What level of automation is economically justifiable?
6. What ERP/WMS system do you have?
   a. How do you use it?
   b. Do you handle incoming orders with it?
   c. Can you use it for other things (as it is not used for now)?
7. What documentation is made in the warehouse?
   a. Do you update physical labels on goods or is it done digitally?

Conclusion

Thanks for the time and participation.

1. Do you have anything else you want to add?

Appendix B - Interview questions for Supply Chain Manager & Head of MCW

Begin by telling who the researchers are, what we are doing, the purpose of the interview, and how long it will take (~1h).

General questions

1. Tell us about yourself?
2. What role do you have?
    a. What kind of responsibilities?
    b. Daily tasks?
    c. Long term tasks?
3. How long have you been employed at Mips?

Network & product characteristics

Output: *Understanding how the corporate strategy affects the network and the warehouse in question. Network map of the material flow to and from the warehouse. Warehouse concept table. Product characteristics identification.*

1. What is the warehouse's key purpose?
    a. What type of DC is it?

Type of DC	Description
Pickup and delivery	Serves local areas. Pickup and delivery activities to customers/suppliers on a daily basis.
Cross dock/consolidation	High speed goods flow, goods are not stored. Consolidation of smaller orders or orders from different suppliers.
Break-bulk	Consolidation to or separation of large units before shipping to customers.
Relay	No goods handling, only change of driver.
Warehouse	Used to meet shifting demands by keeping safety stock.
Transfer	Freight shifts from one vehicle to another.

    b. Do you use KPIs or other metrics in the warehouse?
        i. In that case, which and why?
2. What was important when you chose this warehouse? Layout, design?
    a. What are the requirements of the warehouse for the products?
    b. Do you have any restrictions to follow? Work-related, safety, etc.
3. Are there variations in storage handling units? Different types of pallets etc.
4. What is the lead time for delivery of the current warehouse?

5. What is the average service level of the current warehouse?
6. How are the SKUs delivered? How often, by which vehicle, from where etc.
7. How are the SKUs characterized? Size, amount, weight, value, fragility, stackability, etc.
    a. Do they vary much in terms of packaging or other requirements?

Demand

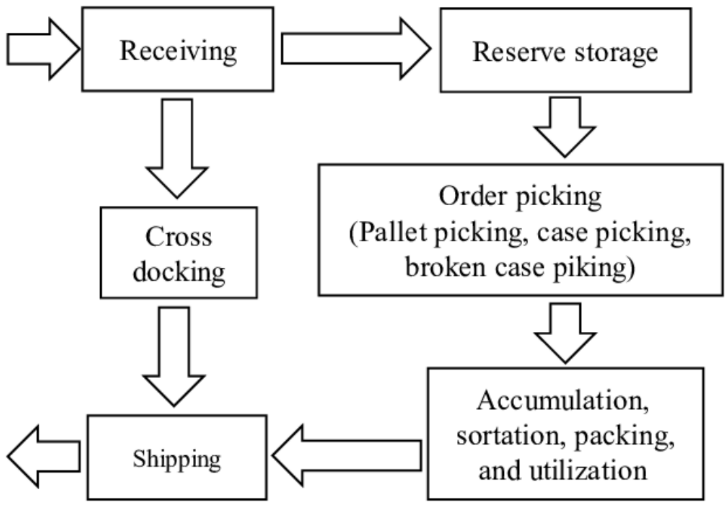
Outputs: *Demand profile for the time frame considered. Scenarios to use as sensitivity analysis.*

1. What is the demand for different SKUs?
    a. Is there any seasonality?
    b. How much safety stock do you have?
2. At peak demand, how do you deal with labor capacity?
3. How often are new products introduced, and how often are products phased out?
    a. For how long do the different SKUs stay in the warehouse?
4. How much are stored suppliers instead of the MCW?
    a. Which suppliers, where, and what products?
    b. What's the cost of it?
    c. What is the reasoning behind it?
5. What are the current costs of the warehouse?
    a. What accounts for the largest spending?

Storage handling & departments

Outputs: *Ancillary activities. Process map over the future state of the material handling process. Understanding the proportion of orders and units handled is of each storage handling unit. Identification of the need for departments regarding storage handling units*

1. How does the current warehouse layout look, and what are its benefits and flaws?
    a. Is it purposefully planned?
2. Could you explain the operations in the warehouse and their flow? Please do it for each department.



   a. Do you have a picture to show entrances and exits for all departments?
   b. Do you have a picture to show where the receiving and shipping dock is located?
3. What are the departments, and how are they related to the operations?
   a. How many people work in each department?
   b. What are the space needs of the different departments?
4. Which ancillary (subtasks) operation activities should be performed in the warehouse?
   a. Do they need to be in specific places?
5. Where is quality control made? At suppliers, MCW, etc.
6. Do you use dedicated or shared locations?
7. Do you have the SKUs assigned to classes or zones?
   a. How are they assigned in that case?
8. How are the reserve and picking areas divided? FPA?
9. How is the picking process?
   a. How is the picklist generated?
   b. What is the average picking efficiency?
   c. What is the average picking accuracy?
   d. Do you use batching?
10. How are the aisles? Amount, location, orientation, dimensions, etc.

Equipment & automation level

Outputs: *Identified automation level. Decision table of equipment setup. Space requirements for equipment setup and storage process.*

1. What types of racks are there, and what is their dimension?
   a. What equipment is complementary to the rack system?
   b. What limitations are set on the rack system by the product requirements and equipment used?

2. What is the handling equipment?
    a. Where is the handling equipment stored?
3. How much of the labor is done manually, and how much with trucks?
    a. What types of trucks is it?
4. What automatic solutions do you have?
    a. Why do you have them?
    b. Where do you have them, in which departments?
    c. Are there any other solutions you might find useful?
5. What level of automation is economically justifiable?
6. What ERP/WMS system do you have?
    a. How do you use it?
    b. Do you handle incoming orders with it?
    c. Can you use it for other things (as it is not used for now)?
7. What documentation is made in the warehouse?
    a. Do you update physical labels on goods, or is it done digitally?

Conclusion

Thanks for the time and participation. Some last questions.

1. How well do you follow the 5S strategy in the warehouse?
2. Can you tell us your thoughts on the new warehouse?
    a. Can you explain the calculations and assumptions you have made for the new warehouse? (Show picture of Excel file)
3. Do you have anything else you want to add?

Appendix C - Calculations

Components added/subtracted

Component 1 have 250 per carton, 28 cartons per pallet. Component 2 have 3600 per carton and 28 cartons per pallet.

$\frac{1000000*4}{250*28*12} =$ 48 pallets when looking at component 1, 4 months stock.

$\frac{4000000*4}{3600*28*12} =$ 13 pallets when looking at component 2, 4 months stock.

$\frac{1000000*6}{250*28*12} =$ 71 pallets when looking at component 1, 6 months stock.

$\frac{4000000*6}{3600*28*12} =$ 20 pallets when looking at component 2, 6 months stock.

Component 3 and component 4, together they will have the same volume as an already existing component (10M 2021). 250000 per package and 30 packages per pallet.

$\frac{10000000*4*1.1^3}{250000*30*12} = 1$ for 10% growth, 4 months stock.

$\frac{10000000*4*1.15^3}{250000*30*12} = 1$ for 15% growth, 4 months stock.

$\frac{10000000*6*1.1^3}{250000*30*12} = 1$ for 10% growth, 6 months stock.

$\frac{10000000*6*1.15^3}{250000*30*12} = 1$ for 15% growth, 6 months stock.

Component 5 will have the same volume as an already existing component (10M 2021) but 3 times as big in physical size. 250000 per package and 30 packages per pallet.

$\frac{10000000*4*3*1.1^3}{250000*30*12} = 2$ pallets for 10% growth, 4 months stock.

$\frac{10000000*4*3*1.15^3}{250000*30*12} = 2$ pallets for 15% growth, 4 months stock.

$\frac{10000000*6*3*1.1^3}{250000*30*12} = 3$ pallets for 10% growth, 6 months stock.

$$\frac{10000000*6*3*1.15^3}{250000*30*12} = 3$$ pallets for 15% growth, 6 months stock.

Component 6, will have the same volume as an already existing component (10M 2021) but 2 times as big in physical size. 250000 per package and 30 packages per pallet.

$$\frac{10000000*4*2*1.1^3}{250000*30*12} = 1$$ pallets for 10% growth, 4 months stock.

$$\frac{10000000*4*2*1.15^3}{250000*30*12} = 1$$ pallets for 15% growth, 4 months stock.

$$\frac{10000000*6*2*1.1^3}{250000*30*12} = 2$$ pallets for 10% growth, 6 months stock.

$$\frac{10000000*6*2*1.15^3}{250000*30*12} = 2$$ pallets for 15% growth, 6 months stock.

Component 7 will have a volume of 25% of an already existing component (10M 2021) but 10 times as big in physical size. 250000 per package and 30 packages per pallet.

$$\frac{10000000*4*0.25*10*1.1^3}{250000*30*12} = 1$$ pallets for 10% growth, 4 months stock.

$$\frac{10000000*4*0.25*10*1.15^3}{250000*30*12} = 2$$ pallets for 15% growth, 4 months stock.

$$\frac{10000000*6*0.25*10*1.1^3}{250000*30*12} = 2$$ pallets for 10% growth, 6 months stock.

$$\frac{10000000*6*0.25*10*1.15^3}{250000*30*12} = 3$$ pallets for 15% growth, 6 months stock.

Racks vs floor storage

Yearly growth linear to growth of rackets.

10% growth: $50 * 1.10 = 55\, racks$

15% growth: $50 * 1.15 = 58\, racks$

55 racks take up: $55 * ((2 * 2 * 0.4) + (2 * 1)) = 198\, m^3$ (1m space between)

58 racks take up $58 * ((2 * 2 * 0.4) + (2 * 1)) = 209\, m^3$ (1m space between)

55 shelves can store: $55 * 10 * 4 = 2200\, cartons$

58 shelfs can store $58 * 10 * 4 = 2320\, cartons$

198 m^3 where each pallet holds 30 cartons: $198 * 30/((1 + 1.5) * 1.2) = 1980\ cartons$
209 m^3 where each pallet holds 30 cartons: $209 * 30/((1 + 1.5) * 1.2) = 2090\ cartons$

$2200 - 1980 = 220\ cartons$ more in racks
$2320 - 2090 = 230\ cartons$ more in racks

Number of models

As of now, the room is $100m^2$ with a total number of 1800 models, from the table it can therefore be seen that 50% more space is needed.

Description	2016	2017	2018	2019	2020	2021	2022	2023	2024
Number of models (Total)	146	233	287	354	421	505	-	-	757
Need of storing (Accumulated)	146	379	666	1020	1441	1800	-	-	2700

Scenario calculation

$$1.\ Yearly\ demand\ pallets = \frac{Yearly\ demand}{Pieces\ per\ box * Boxes\ per\ pallet}$$

$$2.\ Average\ stored\ pallets = \frac{Yearly\ demand\ \ pallets}{Turnaround\ time}$$

$$3.\ Needed\ warehouse\ area = \frac{Average\ stored\ pallets * Peak\ to\ average * Area\ per\ pallet}{Pallet\ utilization\ rate * Floor\ utilization\ rate}$$