LUND UNIVERSITY

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Direct Material Safety Stock Standard

A Study at IKEA Industry

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Keywords: Safety stock, safety time, safety stock under MRP, inventory control, Combining safety stock and safety time, decision support framework

Preface

This thesis was conducted during the spring of 2018 as the final part of our Master's Degree in Industrial Engineering and Management at Lund University. The thesis was written on behalf of IKEA Industry, focusing on their site in Lubawa, Poland.

We would like to express our sincere gratitude to all people that have helped us at IKEA Industry, and a special thanks to Gustaf Lilja for arranging the project and supporting us on a weekly basis. Also, Tomasz Śliwiński deserves to be acknowledged for his hospitality in Lubawa and help throughout the project.

Finally, we would like to thank our supervisor Eva Berg at Lund University who have helped us with valuable comments, support, and feedback during the project.

Abstract

Title: Direct Material Safety Stock Standard

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Supervisors: Gustaf Lilja, IKEA Industry

Eva Berg, Division of Industrial management and logistics, Lund University

Contribution: This thesis has been a complete elaboration between the two authors. Each author has been involved in every part of the process.

Background: In a time when everything is available at the click of a button and consumers are expecting next-day delivery, the work for high service levels is at full speed. Stock is a cost which needs to be minimized, but how low can it go before it has a negative impact on the service levels? In the fast-changing environment, safety stocks have gained a growing importance while the improving production systems have made lower safety stocks a possibility. The question is, what is the correct safety stock level?

Problem description: IKEA Industry is aiming towards higher levels of standardization and unified ways of working. All with the purpose of lowering costs and increasing revenues. In this process, introducing a standard for working with direct material safety stocks is one step in the right direction. Currently, each supply planner is responsible for safety stocks within their area and they may work in several different ways. With a safety stock standard, the scientific parts of this work will increase, the knowledge loss when one quits will be reduced, and further development easier.

Purpose: The purpose is to improve the current direct material safety stock by creating guidelines and a model to standardize the way that IKEA Industry factories handle safety stock.

Research questions:

1. Which factors affect safety stock levels?
2. How do these identified factors affect the safety stock levels at IKEA Industry?
3. How should a standardized tool be developed to be able to continuously estimate safety stock levels at IKEA Industry's factories?

Methodology The approach is a systems approach, taking a holistic overview of a case study at one production site. In addition to the case study, there is a quantitative strategy and analysis to measure the effects of different safety stock methods, resulting in a mixed methods strategy. The quality is evaluated based on its reliability, validity, and objectivity.

Conclusion The initial part of the thesis concludes that the safety stock is affected by seven main factors: demand pattern, service level, lead times, cost of stock, component commonality, order policy, and product quality. For IKEA Industry, four of these factors are extra important: demand pattern, service level, lead times, and cost of stock. Volatile demand patterns and high service levels both require higher safety stock; longer lead times increases safety stock; the cost of stock limits the amount of safety stock.

The standardized tool developed during this thesis considers production deviations, delivery delay deviations, lead times, and a target service level to calculate a suggested safety stock and safety time for each article. Articles are divided into A, B and C-categories depending on their order production frequency. For A and B-articles, a combination of safety stock and safety time is suggested, while C-articles are suggested to only use safety time.

The suggested levels will be presented in a QlikView application. The application allows the user to set the desired service level and ABC-categories. Then the current and suggested safety stock and safety time are presented in a table. The application also shows each part of the safety stock calculations, thus allowing the user to perform analysis for individual articles.

Keywords Safety stock, safety time, safety stock under MRP, inventory control, Combining safety stock and safety time, decision support framework

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1 Introduction

This introduction aims to present the background for this master thesis, followed by a description of the problem, and amounting in the research questions and purpose, with a few delimitations. At the end, the structure for the following paper will be presented.

1.1 Background

Supply Chain Management has been around for a long time. Linking processes of several actors in the value chain to the activities within the company, and making everything work can be a tricky business. However, the concept as such is nothing new. Supplying armies with the right weapons at the right time and sourcing material for building the pyramids have all taken the field of logistics to where it is today (Christopher 2011).

An essential part of Supply Chain Management is Inventory Control, an area that has developed a lot over the last decades. A company's stock level decisions affect not only the working capital, but also the production plan adherence and service levels. One could say that inventory control is the glue linking together other parts in the supply chain by balancing conflicting goals, e.g. between production and purchasing. During the past 100 years, there has been a variety of Inventory Control models, some of which are still used today. However, due to the rapid development of computational power, the models of today can be applied to monitor every single unit in a warehouse (Axsäter 2006, p.1).

One aspect of Inventory Control is to cope with both demand and supplier uncertainty, one option is to use safety stocks, for either finished goods, work in progress, or direct material. The goal is to have enough safety stock to avoid production interruptions, while not having too much capital invested in stock and hence decreasing investment opportunities for other areas. However, warehouse space is an everlasting limitation to the size of stocks and might require less than optimal choices.

In 2006, more than 50 % of companies still used ABC classification or more general rules, such as weeks of supply, ignoring the possibility to optimize stock levels (Enslow 2006), even though Sandvig (1998) derived a method for calculating safety stock based on lead time several years earlier. Schmidt et al. (2012) explores the available methods further by giving an overview of other ways to calculate safety stock, such as the standard model and various extensions of it.

Companies conduct careful analysis and apply financial models when comparing different investment opportunities. If the same carefulness and time was put into managing stock, and safety stock in particular, large saving could be achieved. Still, companies are unaware of these missed opportunities. At a case company, Sandvig (1998) could decrease the total cost of stock by more than 30% by a thorough overlook of their safety stock handling.

Additionally, a well-planned safety stock has several benefits for the societal environment surrounding a company. The main benefit of safety stocks is a smoother production. Thus avoiding emergency shipments which are less environmentally friendly, or reducing the risk of losing business due to stockouts. A well optimized production also maintains a cost-efficient operation, allowing for lower consumer prices. However, there is also ethical aspects to consider regarding automation. While the process becomes more efficient with the digital support tool, it is up to each company to decide what the extra man-hours will be used for. In some cases it could allow for a reduction in the workforce, resulting in unemployment.

To stay competitive, companies have to work actively with inventory. This thesis will investigate which factors affects the safety stock in the case company's direct material warehouse. Direct material refers to materials and supplies that are used during the production process of a product, and can be identified with that product. Moreover, the thesis will conclude if the safety stock at the case company can be improved with regards to service levels, by standardizing the way they handle safety stock.

1.2 Problem Description

Many companies seek to have a near optimal stock level, but with many factors affecting stock level in the supply chain, the optimal safety stock will change constantly. Theory suggests several methods to calculate safety stock. However, since all supply chains work differently, it is hard to know which factors to consider, and which method works best for a specific company. The method and size of the safety stock are both affected by the location of storage in the supply chain, the production strategy, and whether the variations occur in the demand or the supply. Furthermore, Peterson and Silver (1979) noticed that the industry lags in the implementation of company decision rules. Therefore, there exists a gap between theoretical solutions and the real world problems. The target of this thesis is to bridge the gap by looking at a case company to see what solutions would work best for them.

The case company, IKEA Industry, is the largest supplier to IKEA and part of the Inter IKEA group. Currently, IKEA Industry has no standardized way of handling direct material buffers in their 40 factories. There are solutions for finished goods within the company, but the question remains if these are the right ones for incoming materials. The individual sites are currently setting their stock levels based on past experience and gut feeling, knowing that potential production stops due to insufficient stock are undesirable. A lot of knowledge is residing in the co-worker's minds and could therefore easily be lost if the individual retires or decides to work at another company. Since there are only one or a few planners at each site, regaining the lost knowledge will be hard. Scalzo (2006)) argues that these kinds of organizations are the ones suffering most when undocumented knowledge is lost. Moreover, the process of training new people and for them to gain an understanding of reasonable safety stock levels, takes a lot of time and resources. In addition to a low internal rate of return, this might have led to a non-optimal safety stock. Since no internal benchmarks or best practices exist today, it is hard to know how well each site performs. Direct material safety stock levels could be too high as a precaution, considering unwanted stops in production due to lack of direct material. This could lead to safety stocks that are more easily adjusted upwards than decreased, resulting in too high safety stock. A method or best practice of how to work with safety stocks could act as a tool to counteract this behavior.

IKEA Group is growing significantly and thus, elements related to the supply chain gets more critical and needs to be reviewed. Additionally, as IKEA grows, the size of the storage areas could become a bottleneck. Therefore, this thesis will focus on how to standardize the way IKEA Industry works with safety stock for direct material, by implementing a model to aid decision making in all 40 factories. Furthermore, IKEA Industry wants the standardized tool to be understandable and customizable by the individual user, so it can work for their local site. This is connected to IKEA Industry's including culture where the individual coworker should not be stripped from decision-making. Which is similar to the words of Hannerz (1982, p.40):

"Culture includes shared knowledge, values, experiences and connected patterns of thoughts. But it does not only exist inside people's heads. The consciousness becomes shared only by communication, sharing a language, understanding codes and messages, seeing the whole environment as loaded with meaning in a way that is reasonable similar to all - or at least most people."

This reflects IKEA Industry's concern of a tool that completely strips the user's ability to understand the underlying principles. However, there is a risk in keeping things too simple, as Albert Einstein put it: "Everything should be made as simple as possible, but not simpler" (Sandvig 1998).

For a large company like IKEA Industry, the culture of cooperation and expansion provides an opportunity for standardization in alignment with the IKEA way of working.

1.3 Purpose

The purpose is to improve the current direct material safety stock by creating guidelines and a model to standardize the way that IKEA Industry factories handle safety stock.

1.4 Research Questions

Many different factors are involved in the need for safety stock at a company. The first research question is meant to bring clarity to what the important factors are, regarding safety stocks for direct materials, based on the current research and literature.

> RQ 1: Which factors affect safety stock levels?

Understanding how the factors affect IKEA Industry is the following step. By analyzing historical data from the case site to see how different parameters affect the production and cost of capital, an understanding of important factors can be achieved.

> RQ 2: How do these identified factors affect the safety stock levels at IKEA Industry?

The knowledge of all these factors will be incorporated into the development of a framework for future use when dimensioning safety stocks for direct material. This is the purpose of the final research question, which should lead to a tool that can be used in a large variety of different factories.

> RQ 3: How should a standardized tool be developed to be able to continuously estimate safety stock levels at IKEA Industry's factories?

1.5 Focus

While the thesis will investigate and compare different methods for calculating the safety stock for direct material in the factories, the recommendation and created framework will be limited to methods which are likely to be of use to the employees responsible for the safety stock. Methods that are too complicated or are unlikely to be used will not be chosen due to the limited usefulness for IKEA Industry. A useful method should, according to IKEA Industry co-workers:

- Be understandable and not a “black box”. The method should not require a university degree in math to understand the concept of how it is working.
- Not require manual labor on a daily basis.
- Be customizable for each location, i.e. a site should be able to override the method for specific products if they feel the need.

Since the framework is meant to be used in all factories, in different countries, by employees with different backgrounds and level of education, it is important that the framework is easy to use. This means that the framework should feel intuitive, regardless of the employee’s knowledge and experience.

Considering what IKEA Industry wants from this thesis, one of the main issues is to create a framework which actually can and might be used. Thus, one challenge will be to balance the complexity as it may affect how accurate the method is, and making it intuitive and easy to use.

1.6 Delimitations

The thesis will only cover the safety stock of direct material. Hence, work in progress and finished goods safety stock is not considered. This paper will only look at materials that are not solid wood, since they are often purchased, handled, and stored differently than the rest of the materials. Hence, a standardized framework would not be applicable to that category of materials.

Order quantities and lead times are considered to be fixed, i.e. negotiating supplier contracts or changing suppliers is not considered. This also applies to production quantities. Moreover, changes in required storage volume of the suggested safety stock has not been measured due to lack of data.

This project spans a period of twenty weeks. Thus, the time available is limited and the project efforts will be focused to developing a framework based on data from IKEA Industry’s facility in Lubawa.

1.7 Target Group

The thesis is aimed at the supply chain group at IKEA Industry as well as students, teachers, and professors with an interest in Supply Chain Management and Operations Control. To get the most out of the thesis, it is recommended that the reader have some prior knowledge of the above mentioned topics.

1.8 Thesis Structure

An overview of each chapter is presented below with the purpose to give an outline of the thesis.

Chapter 1 - Introduction

The first chapter presents the background of the thesis, and describes the problem, which leads to the research questions and purpose, including a few delimitations.

Chapter 2 - Methodology

The methodology chapter introduces how the master thesis investigation will be performed. The used methods are presented by beginning with an introduction to the different alternatives available and ends with a justification to the chosen method. The chapter begins with the research approach, followed by research strategy, research quality, data collection methods, and ends with the research process.

Chapter 3 - Frame of Reference

The third chapter displays a literature review of the most relevant books and articles. The information presented does not cover all areas extensively, but a good grasp of current research in the field will be obtained. The chapter starts with an introduction to safety stock and some other Inventory Control topics that are necessary for the thesis. The chapter continues with research about product classification and simulation models before it finishes off with pilot studies.

Chapter 4 - Case Description

The chapter will introduce the reader to the case company, IKEA Industry, the case site, Lubawa, and the way safety stock is currently handled. The IKEA Industry's view on stock, an overview of the supply chain and ERP-system will also be covered.

Chapter 5 - Case Analysis and Findings

Chapter five starts by answering the first two research questions and later moves on to how the models were evaluated. The chapter finishes with how the framework for IKEA Industry was developed, how it compares to today's work processes, and the results from the pilot test in Lubawa.

Chapter 6 - Conclusion

The thesis ends with some final conclusions, recommendations to the case company, and a discussion. Lastly, some potential future research topics are presented.

2 Methodology

This chapter introduces a background to how the master thesis investigation will be performed. To present the methods used, each section begins with an introduction to the different alternatives and ends with a justification to the chosen method. The chapter begins with the research approach, followed by research strategy, research quality, data collection methods, and ends with the research process.

2.1 Research Approach

The choice of a research approach is of great importance for the following research and must, therefore, be based on the nature of the research problem. The approach is considered the overall plan for the continued data collection and analysis. By approaching the research with a methodological mindset, it is possible to provide a better understanding of how the research was conducted and the possibility to further continue the work in the future. A framework will not only standardize research, it will also enable discussions regarding the approach (Gammelgaard 2004). Arbnor and Bjerke (1977, p.65) have created a research framework with three different approaches: the analytical approach, the system approach, and the actors' approach. According to Gammelgaard (2004), logistics research is dominated by the analytical approach, but could benefit from more approaches. How the approaches differ from each other is graphically shown in Figure 1.

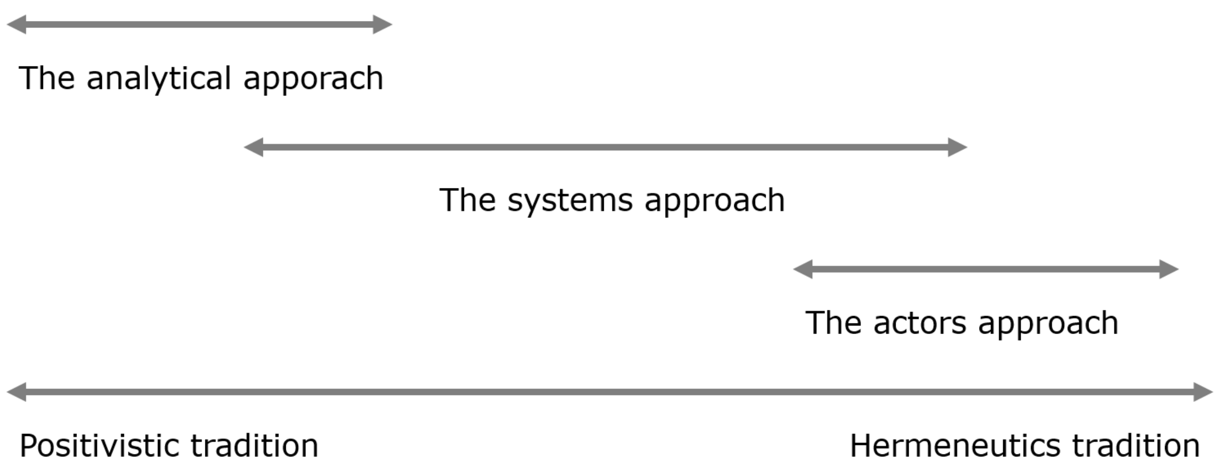

Figure 1. Approach overview. (Arbnor & Bjerke 1977, p.62)

The actors and partly the systems approach are connected to the hermeneutics tradition. This tradition does a distinction between natural science and social science because it considers people as irrational and their behavior cannot be explained, nor have any connection to natural science. Positivism has adopted the natural science model for social science studies and research. One major difference between the two traditions is that the positivistic sees the world as complex, where simplifications are needed to understand it. On the other hand, the hermeneutics tradition believes that a holistic approach is needed. (Arbnor & Bjerke 1977, p.62)

2.1.1 The Analytical Approach

The analytical approach states that there is an objective reality where relations and patterns can be revealed by research. The approach argues that the researcher should not interact with the research object to avoid influencing it. An assumption with the approach is that the study object can be decomposed into elements, i.e. the total is the sum of each component (Arbnor & Bjerke 1977, p.72). Each part can be analyzed and optimized individually. The quantitative data analysis is one of the methods that use the analytical approach.

2.1.2 The System Approach

In difference to the analytical approach, the system approach sees the object as dependent components that has links and feedback mechanisms. To understand it, the researcher must take a holistic approach to the problem and compare different cases rather than finding the cause-effect relation in a decomposed system, i.e. the sum of all components is not equal to the total. The most fitting method is a case study that could be conducted both with quantitative and qualitative methods. (Arbnor & Bjerke 1977, p.72)

2.1.3 The Actors Approach

The actors approach chooses to consider reality, not as an objective fact, but rather a result of various social constructions. This would also mean that knowledge is interpreted as socially constructed and being dependent on the researchers' interpretation. For the researcher to fully understand and construct the future, they ideally need to be part of the research reality, i.e. have the same social constructions as the reality they are researching. Thus, an understanding of reality requires an investigation of intentions to understand the social reality. (Gammelgaard 2004)

2.1.4 The Inductive, Deductive, and Balanced Approach

Supplementary to the approaches described by Arbnor and Bjerke (1977) there is the inductive, deductive, and, if combined, the balanced approach.

Inductive Approach

For complex or dynamic systems, the most common approach is the inductive approach. The inductive approach, also known as the qualitative approach, has various denotations such as naturalistic, humanistic, and interpretive. The main aim of the approach is to "understand the phenomenon in its own terms" (Hirschman 1986). Therefore, the first step is often data collection, mainly consisting of field visits with the goal of observing the phenomenon in a natural setting. Literature review is not set as a separate stage, but is rather consistently embedded in all stages. (Golicic et al. 2005)

The second stage attempts to describe the phenomenon from the informants' point of view. Multiple data sources are examined and techniques such as open-ended questions are used to get a qualitative result and understanding. Finally, a substantive theory is built based on the data collected. (Golicic et al. 2005)

Overall, the focus of the inductive approach is to describe the phenomenon with field data, and often theories cannot be adapted completely or the research field is rather new (Golicic et al. 2005). This approach is mainly used in Supply Chain Management, since the involvement of several firms makes the area ill structured and messy (Näslund 2002).

Deductive Approach

Deductive on the other hand, also known as the quantitative approach, is identified with terms such as positivism, logical empiricism, and realism. The approach starts with a literature review to establish a conceptual framework with relevant variables and their expected relationships. Afterwards, a formal theory is built, with the ability to create predictive statements to be tested with real-world data. The third step consists of careful data collection, which is to be used to test the created model. (Golicic et al. 2005)

The overall focus of deductive approaches are well known concepts in new contexts. This approach lets the researcher develop a formal theory applicable to a bigger picture, outside of the case. (Golicic et al. 2005)

The Balanced Approach

By combining the two methods, i.e. by going back and forth between the inductive and the deductive approach, a balanced approach is achieved. Often the process starts with the inductive approach to understand the area and later on the deductive approach is used to create a formal theory. (Golicic et al. 2005) The process can be found in Figure 2.

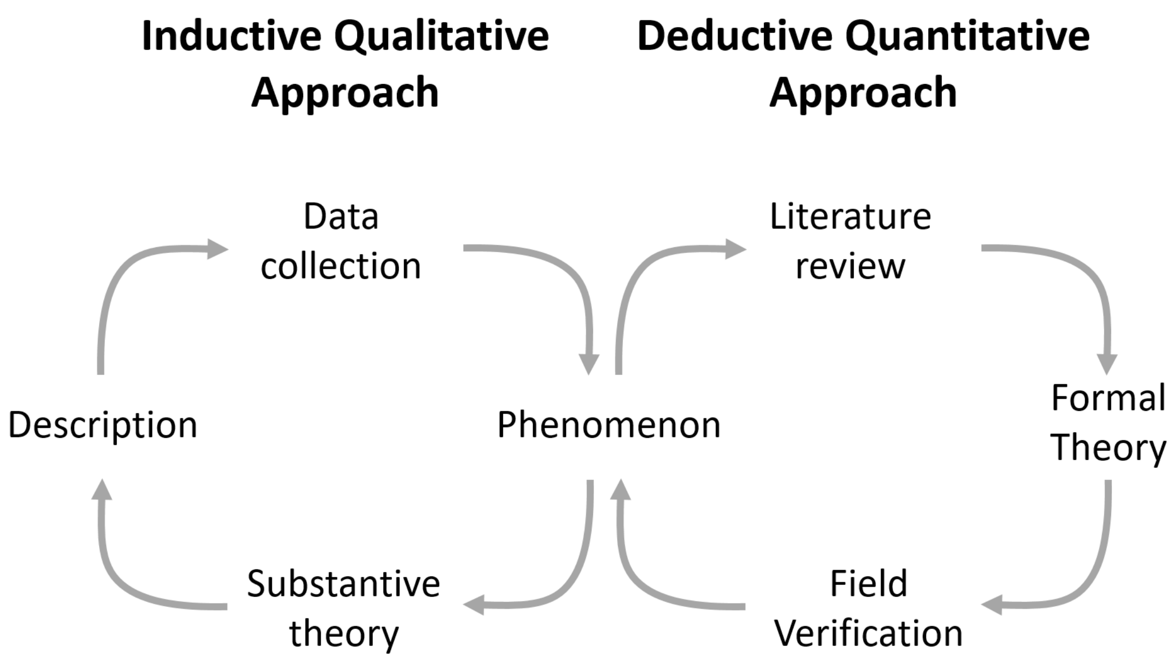

Figure 2. Balanced approach model. (Golicic et al. 2005)

2.1.5 Thesis Approach - System and Balanced Approach

This thesis will have a systems approach, including a case study. To understand what factors affect direct material safety stock levels in the case of IKEA Industry, a holistic approach is needed. It facilitates the full supply chain perspective, and helps to avoid developing a suboptimal solution by analyzing each individual part as in the analytical approach.

The purpose is to develop a standardized way to handle direct material safety stock at several sites. Therefore, a holistic approach is suitable, rather than decomposing the elements to try to find cause-effect relations. Looking at site-specific conditions could be done, but a holistic view is more suitable for the overall goal of creating a standardized tool applicable for all sites. Furthermore, there might be components that are dependent on each other and can therefore not be summarized as in the analytical approach.

Operations research and inventory control are topics that are widely researched. However, since no supply chain is exactly the same, results from other case studies can be indicative, but cannot be taken as a fact and applied to IKEA Industry's supply chain. Because of this, a balanced approach is suitable for the thesis. With areas that are extensively covered in research and case specific limitations, both formal theories and company data will be used. The formal theories will be studied and applied with alterations to fit the case company's specific limitations, and the insights gained from interviews.

2.2 Research Strategy

There are many ways to perform research. For small-scale, low-budget projects with a limited time frame, such as a master thesis, the number of alternatives decreases. However, there are still many strategies available. Denscombe and Martyn (2010, p.4) propose that there are three questions to consider when choosing a strategy:

1. Is it suitable?
2. Is it feasible?
3. Is it ethical?

For a thesis and research alike, Denscombe and Martyn (2010, p.5) suggest considering the following strategies: Surveys, Case studies, Experiments, Action research, and Mixed methods.

2.2.1 Surveys

Surveys are used to measure aspects of social phenomenon and trends, or to collect data in order to test a theory. It is one of the most frequently used methods for social research, mainly since it is a cost and time efficient strategy to gather information from many people. However, the information gathered is generally not so deep, which makes it unsuitable for complicated facts or deep investigations (Denscombe & Martyn 2010, pp.11–12). There are three types of surveys; exploratory, confirmatory, and descriptive survey research.

In exploratory research, surveys are used when there is a need to get new insights on an area that has not been studied deeply before. This can provide insights for future research. For confirmatory research, the goal is to test theories on a phenomena. Lastly, descriptive survey research is mainly used to test the relevance of a phenomenon on a population. (Forza 2002)

2.2.2 Case Studies

Case studies target one, or at most a couple of objects of study to get an in depth view of relationships between processes in a particular setting. The purpose is to see if it is possible to draw general conclusions from a particular case object, i.e. the possibility of application on a case company can be used elsewhere. Compared to surveys, a much more in-depth view can be taken and the object of study can be assessed in more detail (Denscombe & Martyn 2010, p.53). Case studies aim to study a decision; why it was taken, how it was implemented, and the results of it (Yin 1994, p.12).

In difference to an experiment, the case object is studied in its real-life setting and there is not a generated setting for the research. Furthermore, the boundaries between phenomenon and context are not evident (Yin 1994, p.13). This approach is applicable when processes and relationships are of essence, and it can be used in both discovery led and theory led research to either apply a known theory, compare settings or to as a tool for exploration (Denscombe & Martyn 2010, p.55).

2.2.3 Experiments

Experiments are used to explore the cause or to determine the cause of something under controlled conditions. The purpose of the controlled conditions is to be able to isolate specific factors to observe what happens in detail. To measure the effect, a control group or randomized trial is used. Experiments are often used when it is possible to control all variables, except for the observed one. (Denscombe & Martyn 2010, pp.65–76)

2.2.4 Action Research

The defining characteristic of action research is that it is of practical nature. It aims at solving problems in an organizational setting and it involves a feedback loop where findings change the characteristics later on (Denscombe & Martyn 2010, p.126). It is applicable to problems that are highly unstructured, yet it is not widely used in Supply Chain Management or Operations Research (Müller 2005).

2.2.5 Mixed Methods

A mixed method strategy combines several approaches, such as both qualitative and quantitative methods, in the same project. In other approaches it is either a qualitative approach or a quantitative one, but in a mixed strategy the strength is the use of triangulation between different approaches. This could improve the accuracy and possibly eliminate biases in a certain method (Denscombe & Martyn 2010, pp.137–140).

2.2.6 Thesis Strategy - Mixed Method Strategy

This thesis will use a mixed method strategy based on a case study and a quantitative approach to get an in depth view of IKEA Industry´s direct material safety stock. The level of detail is higher than for a survey strategy and applicable data will be gathered from both interviews and company data, instead of solely surveys. An experimental strategy is not feasible due to the inability to control variables in a complex system. Action research strategy could be possible, but due to lack of previous usage in a Supply Chain context and the potential time required for an iterative process the action research strategy was deemed unsuitable. Through a case study, the involvement of the case site is improved and thus creates an ethical approach where a larger part of the organization is involved. For a more extensive overview of case studies and quantitative approaches, please see section 2.4.

By combining both the qualitative aspects of a case study with the analytical aspect comparing safety stock methods at the case company, both the "which" and "how" research questions can be answered. However, the focus will be on the third question, with the first and second questions being prerequisite to answer the last one.

2.3 Research Quality

As is the case with all research, the quality and credibility of the research process cannot be taken for granted, and must be demonstrated through the process. Readers cannot be expected to trust the message with pure faith. It must be proven by using good research methods and sources. Three of the most common aspects of research quality are reliability, validity and objectivity. A graphical representation of reliability and validity can be seen below in Figure 3.

2.3.1 Reliability

Reliability is a measure of the neutrality of a research instrument, whether it would be consistent over multiple uses on different occasions. It can also be interpreted as a question regarding if the research instrument would give the same result on a different occasion. To enable this increase in dependency, the principle way is for researchers to be as open as possible with their research process. This includes showing the readers what methods and analysis has been used, as well as what decisions have been made and how, creating a process open for audit. (Denscombe & Martyn 2010, pp.298–300)

2.3.2 Validity

Validity concerns the accuracy and preciseness of the data. Additionally, it also refers to whether or not the data is appropriate for the investigated research question. The issue of validity is how it can be measured in qualitative research. It is uncertain whether it is even possible to prove that a researcher has understood everything correctly. Therefore, the word credibility is often used instead of validity. Steps can be taken to show that the data used is reasonably likely to be accurate and appropriate: (Denscombe & Martyn 2010, pp.298–299)

Triangulation - By using multiple data sources, preferably with some contrast to each other, researchers can increase the probability that the data is good.

Respondent Validation - By returning to the participants with the collected data and any findings, the participant can confirm or reject the data. However, there are some limitations in that the research might be beyond the grasp of the participant or the participant might dislike the findings.

Grounded Data - In qualitative research, a common method is extensive use of fieldwork during the data gathering. This provides a good foundation for the following research and adds some credibility.

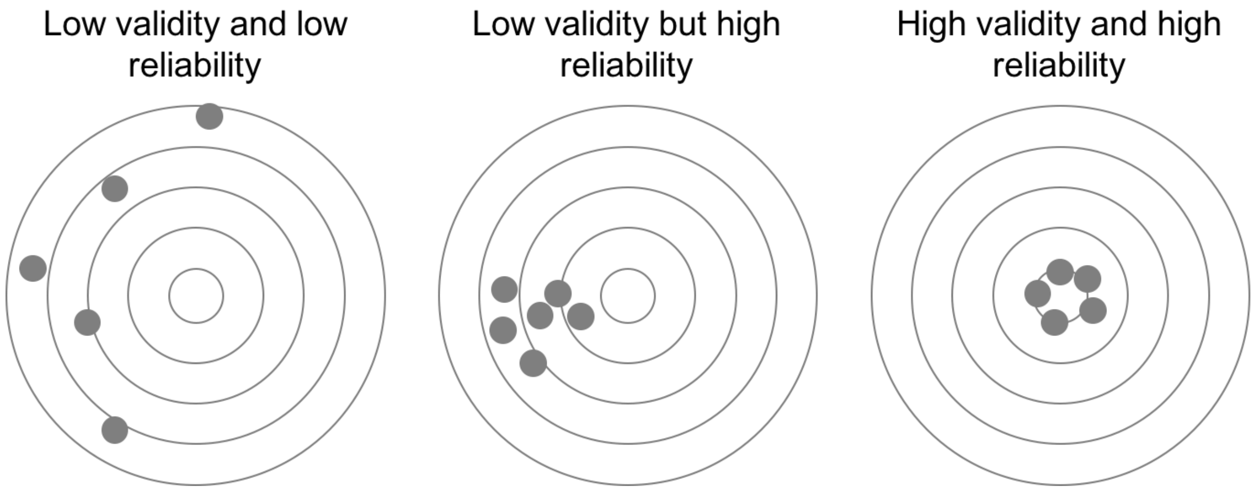

Figure 3. Validity and reliability. (Björklund 2003, p.60)

2.3.3 Objectivity

Objectivity focuses on how the researchers can influence the outcome of the research. The research should be free of any bias, be impartial and neutral to any influence, and have a fair analysis. However, this is no easy task since all qualitative research is dependent on how the researcher interprets the available data, which is always influenced by the social constructs of the researcher.

With this in consideration, there are some pointers to follow: be aware of the self in qualitative research; reflect about how the research has been influenced by personal experience and values; keep an open mind. By demonstrating to which extent the authors have kept an open mind, readers can form a personal opinion to how objective the research can be expected to be. (Denscombe & Martyn 2010, pp.298–304)

2.3.4 Thesis Quality

The reliability of this thesis will be ensured by thoroughly documenting the approach and assumptions, as can be seen in the succeeding chapters. Moreover, stakeholders from both the case company and the University will be updated on at least a weekly basis to ensure a transparent process.

The thesis validity will be ensured by collecting data from the ERP system, combined with interviews to make sure that the data is reliable and appropriate. ERP experts at the case company will provide the authors with the needed knowledge to guarantee that the data is up to date. Additionally, the data that the thesis will use is also used in the daily operation, meaning that employees rely on the same data as the thesis will.

As for objectivity, the authors will try to be transparent and document their decisions during the thesis. By having clear communication with stakeholders, different perspectives will be taken into consideration. However, it is impossible to ensure that the authors are completely free of any biases.

Therefore, the midterm seminar and other presentations throughout the project will be of essence to get a neutral perspective.

In addition, the following steps have been taken throughout the project to ensure high quality:

- The sources in the literature review will mainly come from well-accredited databases and will be listed in a literature search document to ensure quality and transparency, see Appendix A.
- No simulation model can completely represent reality. The assumptions and simplifications made in order to build the model have to represent reality. Therefore, all assumptions in the simulation model have been discussed and approved by both planners and managers, to ensure that the quality of the results is as high as possible.
- Due to the relatively short time frame of the project, full-scale testing will not be possible beyond the simulation. A smaller test will be conducted at the case site, but any conclusions should not be drawn before conducting a larger test. Therefore, the conclusions will mainly be based on the simulation.

2.4 Data Collection

2.4.1 Primary and Secondary Data

Data collection can be divided into primary and secondary data collection. The primary data includes data specifically for the purpose of this study. This includes interviews, surveys, and observations where the research team gathers information for the purpose of their study. Furthermore, case specific data such as company data from an ERP-system is regarded as primary data (Björklund 2003, p.68).

All data that is not collected for the purpose of this research topic is defined as secondary data, such as a literature review or censuses. When using secondary data the researcher should review it critically, since the information could be biased, come from an untrusted source, or that it might not be applicable to the research in question (Björklund 2003, p.67).

2.4.2 Literature Review

A literature review can be a valuable addition to the research process in many different ways. It has two main functions: The first is to summarize the existing research and provide a basis upon which ideas for new research can be found. Thus, it provides a starting point for research. The second function is to provide a research base to which the new research can be related to.

Seuring et al. (2005) present a process model for content analysis, suggested by Mayring (2015), which creates a mixture of qualitative and quantitative methods, containing four steps:

1. **Material collection:** A definition and delimitation of the material which should be collected. This may include the research method or where it was published.
2. **Descriptive analysis:** Makes a statistical evaluation of the gathered material, going through formal aspects e.g. number of publications per year.

3. **Category selection:** The selection of structural dimensions and related analytic categories, whose purpose is to structure the field. The various analytical categories are covered by major topics formed by the structural dimensions.
4. **Material evaluation:** Analysis of the material and sorting according to the structural dimensions and categories. The aim is to make relevant issues identifiable and the results interpretable.

The classification of the literature, consisting of structural dimensions and related analytic categories can be derived before or after the material analysis. Since all contents will need to be comprehended by the researcher, involving more than just one researcher will reduce the risk of incorrect comprehension and in extension, faulty analysis. (Seuring et al. 2005)

The thesis will have a structured approach for literature review, to ensure that only relevant and high quality literature is used. Literature will firstly come from well-accredited databases such as; EBSCO Host, JSTOR, Elsevier, and Emerald. Additionally, a literature search document will be established to ensure that all relevant keywords will be covered, see Appendix A. The document will also provide transparency for the search process.

2.4.3 Case Study Research

"A case study is an empirical enquiry that (1) investigates a contemporary phenomenon within its real life context, especially when (2) the boundaries between phenomenon and context are not clearly evident" (Yin 1994, p.13). They can be used as a research method in cases where contextual factors are considered but also limiting the analysis. Thus, it enables an in-depth insight with conceptual developments. According to Yin (1994), three kinds of case studies can be distinguished:

1. **Exploratory case study:** to explore a situation where the studied intervention does not have a clear set of outcomes.
2. **Descriptive case study:** to describe a real-life application and in which context it happened.
3. **Explanatory case study:** to explain the links between real-life interventions which are too complex for experimental studies or surveys.

Case studies can be used for four major purposes: exploration, theory building, theory testing, and theory extension. It is important to consider which of the strategies can be applied in a situation. (Seuring 2005)

Regarding the research process of case studies, Stuart et al. (2002) propose a process consisting of five steps, as shown in Figure 4:

Figure 4. The five-stage research process model. (Stuart et al. 2002)

Stage 1 - Research Question:

The first step of the case study is to define the research question that will be investigated. There is no consensus to how much existing frameworks should guide the case investigations. Using existing literature can be of use to provide a stable ground for the emerging theory. However, there is also a risk that the predetermined decisions might make the data collection too narrow and important parts may be overlooked. On the other extreme, having a very loose design might be a waste of time. Some researchers have chosen to advocate the middle ground instead, preferring a continuous mix between the two. (Koulikoff-Souviron & Harrison 2005)

Stage 2 - Instrument Development:

With the research question as a basis, the case selection can begin. It is important to carefully choose cases to avoid unrelated variations as much as possible. Pettigrew (1990) proposes three criteria for case selection: (a) use extreme situations, (b) use polar types which can disconfirm patterns in the other study, (c) use high experience level. (Koulikoff-Souviron & Harrison 2005)

Stage 3 - Data Gathering:

The data gathering process is of great importance for the continued research, there is always a limit to how much data can be gathered and thus, the data must be well chosen. Case studies often use a flexible data collection, typically with multiple data collection methods to allow triangulation. It is also important to know when to stop collecting data. Increasing the richness of data is resource intensive and takes time, but it adds convergence and clarification. Gathering additional data after saturation is achieved will only contribute to a mental satisfaction. (Koulikoff-Souviron & Harrison 2005)

Stage 4 - Data Analysis:

The data analysis can be characterized by three main components: data reduction, data display and conclusion drawing. The first component is the data reduction, which is the process of making clear, structured data from the sometimes quite messy field-notes or transcriptions. This makes the data more organized to prepare for conclusion drawing.

With the clear set of data, there is a need for further reduction. Data display aims to help researchers see patterns by reducing the set of data to a smaller, representative basis. This is heavily tied to the conclusion drawing, as writing up conclusions may create a need for changes in the data display, which might lead to further conclusions. (Koulikoff-Souviron & Harrison 2005)

Szopa (2010) argues that simulations are a great tool for analyzing data for systems that are complex and dynamic. A positive aspect of simulations is that a simulation creates more than an answer, since the cause and effect relationships of parameters are traceable. However, a model is only a simplification of the real world, and the results from a simulation should be seen as an approximation.

Stage 5 - Dissemination:

Finally, after making conclusions based on the gathered data, there is a need to validate whether the findings are any good (Koulikoff-Souviron & Harrison 2005). To ensure the validity and quality of the case research, Yin (1994, p.33) has introduced four tests.

- **Construct validity:** The set of measures should be sufficiently operational and avoid any subjective judgement.
- **Internal validity:** Conclusions can be validated by checking if the data patterns are compatible with the patterns expected from the theory. Thus, establishing that the correct cause and effect relations have been found.
- **External validity:** The findings should be compared to the broader theory to get an understanding of if the findings can be expected to apply outside of the studied population.
- **Reliability:** With a case study protocol ensuring that the data gathering is well documented and a case database ensuring traceability, the research process should be documented well enough to enable that the data can be duplicated despite being gathered by someone else, at another time.

The case study can provide a way to study an empirical topic with predetermined procedures. While there are some situations which might differ a lot from the common theories and thus make for suitable candidates for a case study, other situations may lack a clear choice and be best suited for a combination of different methods. This thesis aims to follow the same five stage approach as mentioned above.

Unit of Analysis

The unit of analysis is the direct material safety stock in one of IKEA Industry's factories located in Lubawa, Poland. This factory will act as a representation of all 40 factories. The safety stock considered is the product categories Flatline, Board, and Solid Wood where 23 representative items have been chosen to reflect the direct material as a whole. These articles are the basis of the analysis and they are carefully chosen by the planning team in Lubawa to cover all material groups and product types. For the quantitative part, data for the chosen products were extracted from the ERP-system M3. The data covered the period 2015.02.01- 2018.02.01 for all requested items at the case site Lubawa. The extracted data can be found in Table 1.

Lubawa was chosen as a case site for two reasons. Firstly, Lubawa has noticed that their safety stock handling could be improved, both in the perspective of how to decide stock, and on how much time they are spending. Their current system requires a lot of manual work, a standardized method could free up a lot of man-hours to other activities. Secondly, Lubawa is a large site containing many articles. If Lubawa would implement a safety stock model successfully, the other sites would be more inclined to do the same, reducing the resistance to change.

Table 1. Extracted data used for analysis.

Production orders	Purchase orders
Manufacturing order number	Warehouse
Item number	Item number
Production date	On-hand balance
Order quantity	Order quantity
	Received quantity
Warehouse	Lead time
Safety time	Minimum order quantity
Safety stock	Order multiple
	Requested delivery date
	Actual delivery date

2.4.4 Interviews

When conducting interviews, the main goal is to gather data and gain insights in the opinion of the interviewee. For a quantitative interview, the choice of interviewees should be representative of the entire population, so that conclusions can be made regarding the opinion of the population. A qualitative interview, on the other hand, focuses on choosing the right people for interviews, skipping any random choices. The choices should cover a number of chosen categories which may have important insights. With this approach, no conclusions can be made regarding the population, but the area of interest can be deeply investigated. (Höst et al. 2006, pp.89–92)

There are three main kinds of interviews: unstructured, structured, and semi-structured, interviews. The unstructured interview mainly focuses on a few areas of interest and is otherwise open to take a new direction. Questions may be rephrased, changed or asked in a different order during different interviews. With the unstructured progress, it becomes easier to steer the conversation into interesting areas as they are discovered during the interview. However, there is also a risk that an important area is missed because the interviewee is uncomfortable talking about it. The structured interview is in essence an oral survey, with the advantage of being able to explain any misunderstandings, but it also takes a lot of time. As a mix of unstructured and structured interviews, the semi-structured interview consists of a mix of structured questions with alternatives and open questions that may be adjusted to the interviewee. (Höst et al. 2006, pp.89–92)

The strength of conducting interviews is the access to information of direct relevance to the study. It is also possible to achieve a deeper understanding by adjusting questions based on the responses and interpretation of body language and other signals. (Björklund 2003, p.70)

The thesis will mainly use unstructured interviews to be able to understand what factors that the case company considers important, and not being tied to a formal template.

2.5 How the Study was Performed

The theoretical part of the methodology has been presented in the previous sections of this chapter, this section will cover how the thesis was conducted. A project timeline can be found in Figure 5.

The project process began with an introduction of the proposed project by our supervisor, Gustaf Lilja. Gustaf presented the purpose from IKEA Industry's point of view and introduced us to some of the stakeholders. To get a more elaborated introduction, interviews were held with key stakeholders of the project during December to February, which provided an overview of the expectations and delimitations of the case company. Table 2 provides a summary of all the interviews conducted during the project process. With interviews as a basis, preliminary research questions were set up after discussions with IKEA Industry and LTH.

Table 2. List of interviews.

Interview	Date	Interviewee	Type	Topic	Method of documetation
1	08.12.2017	Conny Svensson - Logistics Manager Flatline	Unstructured	Overview of IKEA Industry, Stock policy, Product classifications	Notes
2	11.12.2017	Peter Mowitz - Supply Chain Manager	Unstructured	Dynamic decition process, Where to keep stock in the supply chain	Notes
3	14.12.2017	Ratislav Bachar - Sales & Supply planning manager, Division board	Unstructured	Overview of board division	Notes
4	18.12.2017	Johan Thuresson - Supply Chain Manager, Business process development	Unstructured	Current Safety Stock usage	Notes
5	18.12.2017	David Engvall - Controller Purchase	Unstructured	Available data	Notes
6	19.01.2018	Emelie Steckel - Solution Owner	Unstructured	ERP and its functions	Notes
7	01.02.2018	Magnus Jensen - Solution manager, Business systems	Unstructured	Qlik and its functions	Notes
8	02.02.2018	Andrzej Paetz - Logistics developer	Unstructured	Safety stock project for finsihed goods	Notes
9	05.02.2018	Charlotte Arvidsson Richter - Process leader	Unstructured	Planning process	Notes
10	08.02.2018	Agnieszka Prześniak - Purchaser, Orla Poland	Unstructured	How the Orla site is working with safety stock and product classification today	Notes
11	13.02.2018 - 14.02.2018	Marie Sommansson - Purchaser, Hultsfred	Unstructured	Study visit to the factory, safety stock and product classification	Notes
12	16.02.2018	Tomasz Sliwinski - Purchaser, Lubawa Poland	Unstructured	How the Lubawa site is working with safety stock and product classification, introduction to pilot	Notes
13	12.03.2018	Filipe Borges - Solution owner	Unstructured	Data extraction from the ERP system	Notes

The second step was to establish a theoretical understanding to be able to answer the research questions. Books and articles have been the main source of information. To ensure getting secondary information of high quality, articles from well-esteemed databases, such as ISI Web of Science, Emerald and EBSCO Host, has been the main source of information. Keywords used in the search included, amongst others, *warehouse management*, *inventory control*, *safety stock*, and *material handling*. Some examples of how the literature review was conducted can be seen in Appendix A.

To understand how an IKEA Industry factory work, a Study visit to IKEA Industry Hultsfred was conducted. The visit gave an increased understanding into some differences between different facilities, how people in different roles have different opinions and input on certain subjects, and a first look into how the safety stock process works. The facility is interesting due to its unusually high degree of automation and relatively small size. However, this also made it difficult to draw any general conclusions for how a typical IKEA Industry facility works.

With the theoretical base and some understanding of how the facilities work with inventory control, the work moved on to a comparison of the different safety stock methods. The comparison was mainly based on 23 articles, suggested by the planning department in Lubawa as a good representation of their articles. A simulation model was constructed in Excel based on data from the 23 articles, which simulates a full year for each article to test what service level each method could reach.

Once the simulations were done and data extracted, a decision was made together with the supply chain managers regarding which method to continue working with. An Excel tool was developed as a first draft for the framework which the planners can use to set safety stock levels. After that, work with a QlikView application was initiated, and a project communication package, including a manual, was developed for the end users.

The production site in Lubawa acted as the pilot site for the thesis. Once the Excel tool was developed it was introduced to the planners at the site to get some user feedback. Moreover, the suggested safety stock method is currently being tested on a selected number of direct material articles to verify that it works, both on a system level and that it delivers the desired service level results.

Finally, the report to both the case company and the University was completed and presented to both parties.

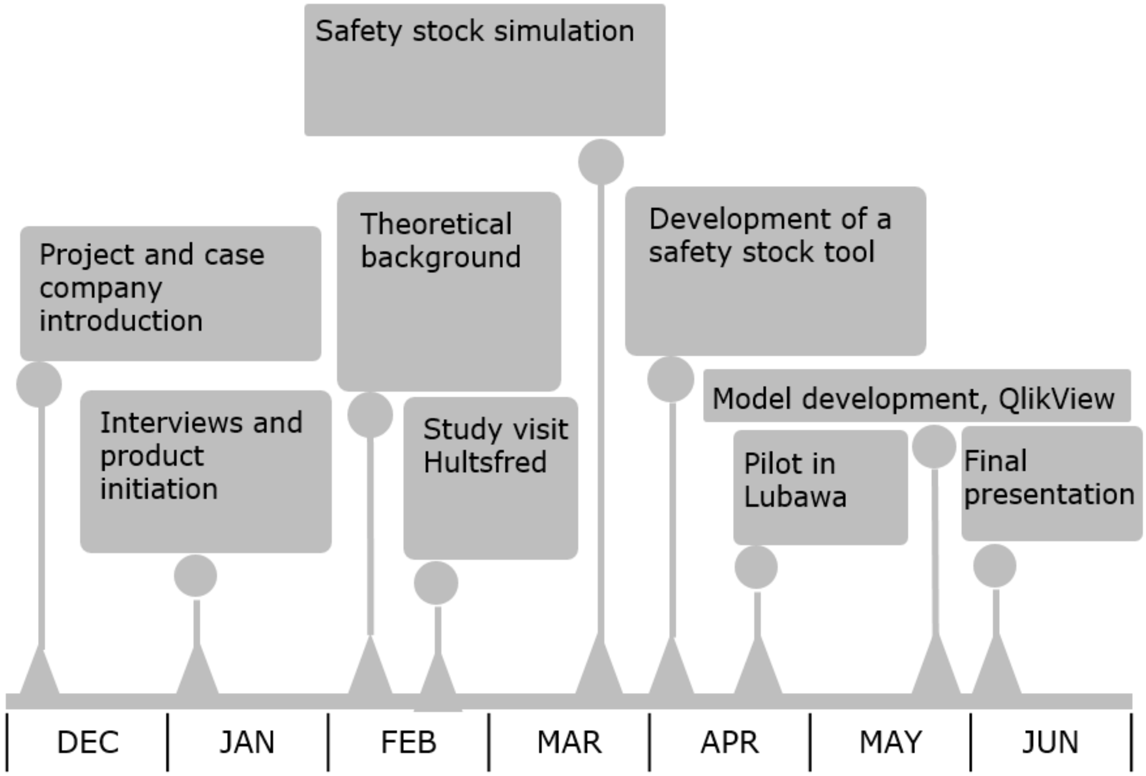

Figure 5. Project timeline.

2.6 Summary of Method

The method has been summarized in Figure 6 to get an overview of the steps.

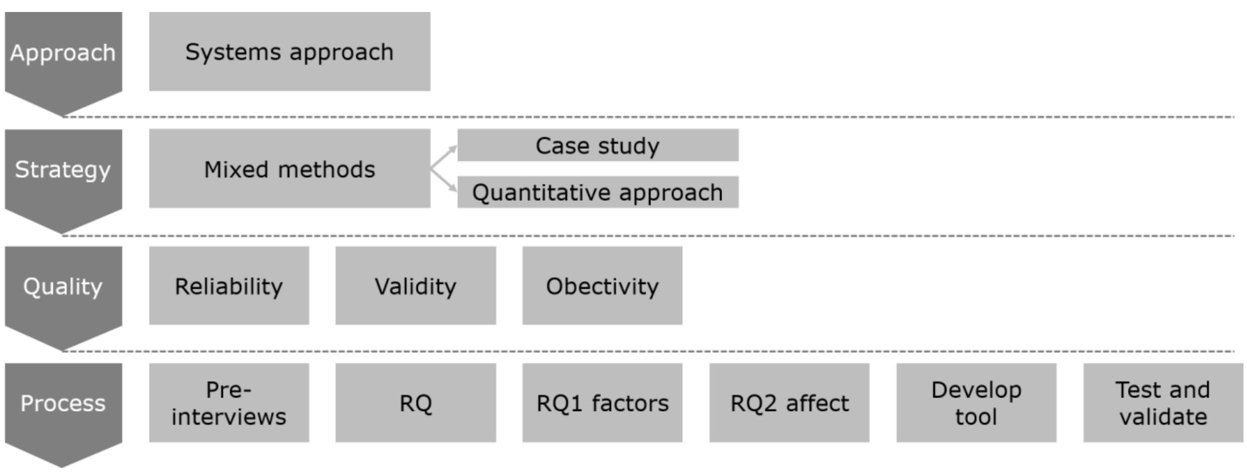

Figure 6. Summary of the chosen method.

The approach has been a systems approach, taking a holistic overview of a case study at one production site, similarly to the overview that many supply chain projects take. However, even though a holistic approach has been applied, there has been a strict focus on inventory control, and direct material safety stock in particular.

In addition to the case study, there was a quantitative strategy and analysis to measure the effects of different safety stock methods, by building a simulation model. The combination resulted in a mixed methods strategy.

The quality has been measured on its reliability, validity, and objectivity. The reliability of this thesis was ensured by thoroughly documenting the approach and assumptions throughout the project. Validity was increased by collecting data both through interviews and the ERP system, i.e. triangulating to ensure the data is correct. Lastly, the authors have tried to work objectively by collecting thoughts and input from several persons and production sites, while trying to keep an open, but critical mind to the information collected.

The thesis process started with pre-interviews to get an overview of how the processes work at the case company, and the current state. Research questions based on the current state were drafted and then answered, either by the literature review or by case findings. Finally, a safety stock tool was developed that considered current literature and case specific factors. The tool was tested at one of the case company's production sites, and finally validated.

3 Frame of Reference

This chapter covers a literature review of the most relevant books and articles. The purpose of the information is not to cover all areas extensively, but to get a good grasp of current research in the field, while focusing on the important parts, i.e. safety stock. The chapter starts with factors that affect safety stock, different safety stock methods, safety stocks under MRP, safety time calculations and product classifications. The chapter ends by covering simulation models and pilot studies.

3.1 Introduction

3.1.1 The Thesis in a Supply Chain Context

The topic of supply chain management covers many areas such as transportation, warehousing, planning, and financing. These topics can be applied to all areas of the extended supply chain, as can be seen in Figure 7 (Scott et al. 2011, pp.5–6).

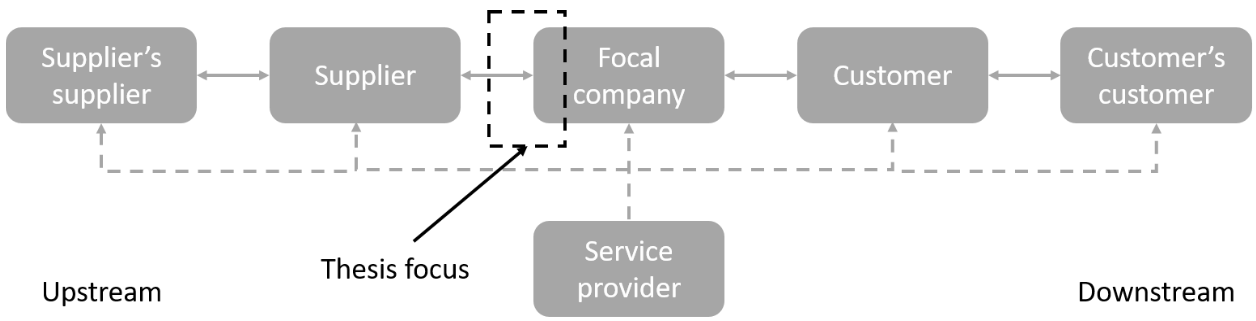

Figure 7. The structure of the extended supply chain. (Scott et al. 2011, p.5)

The thesis and the following chapter will focus on the area connecting the supplier and the focal company, as can be seen in Figure 7. The inbound stock is one of many stock points in the supply chain. It is the first that is owned by the focal company, and one part of the inbound stock is the direct material safety stock that covers deviations in demand and supply.

The direct material stock differs from stocks of finished goods by shifting the link to the rest of the supply chain. Instead of having a forecast to predict customer demand, the demand is close to known as the production plans are made. On the other side, the supply becomes more difficult to predict as own production is replaced by suppliers. The shifted environment enables the use of a MRP-system, further considered in section 3.5.

All this is linked together with several IT-systems, such as ERP systems. Systems like ERP systems can help the focal company with answering questions such as which items are required, the quantity, and the availability (Ganesh et al. 2014, p.3). Which of the factors that affect safety stock will be covered in this chapter.

3.1.2 Chapter Overview

The literature review aims to cover research questions as illustrated in Figure 8. RQ1 is answered by the literature review introducing the factors in section 3.2, while RQ2 and RQ3 is introduced in the following sections of the chapter and then answered in the later chapters.

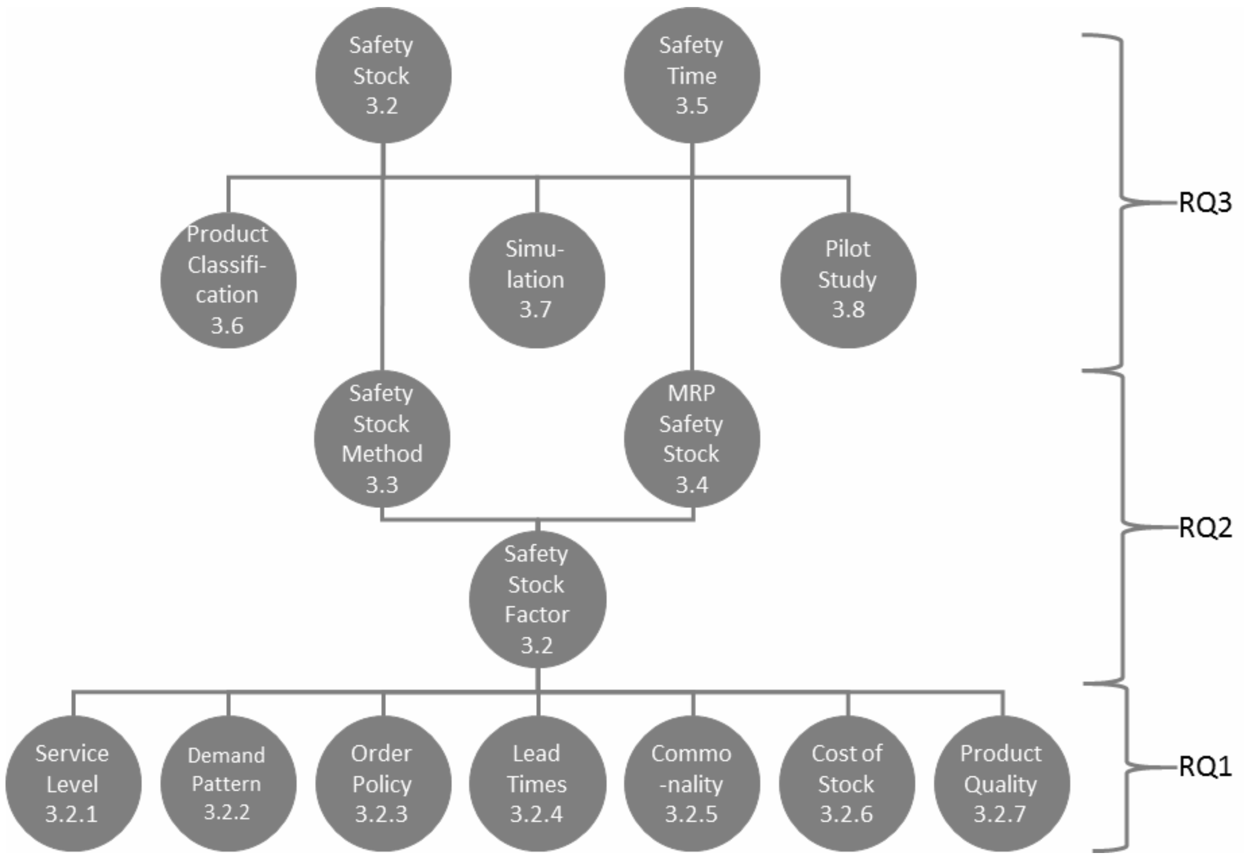

Figure 8. Summary of the conducted literature review.

3.2 Factors Affecting Direct Material Safety Stock

There are conflicting goals within companies regarding how to handle inventory. While the inventory manager wants to keep stock levels low to save money on inventory and inventory space, the purchaser may want to achieve discounts by buying large batches, and the production manager wants to reduce setup time by producing in large batches. Thus, there needs to be a balance between economies of scale and uncertainties. The need for safety stocks is born in the uncertainties in supply and demand, which make it difficult to maintain the exact needed stock without risking stockouts. (Axsäter 2006, pp.1–2)

The need for safety stock often originates in demand uncertainties. Due to lead times and ordering in batches, there exists a time between order placement and material delivery. To reduce the issue of uncertain demand, demand forecasts are used. The variabilities in both demand and lead time affect the level of safety stock, as can be seen in Figure 9 (Oskarsson et al. 2013, p.241). Depending on the uncertainty of the forecast, the safety stock may require different sizes. (Axsäter 2006, p.7)

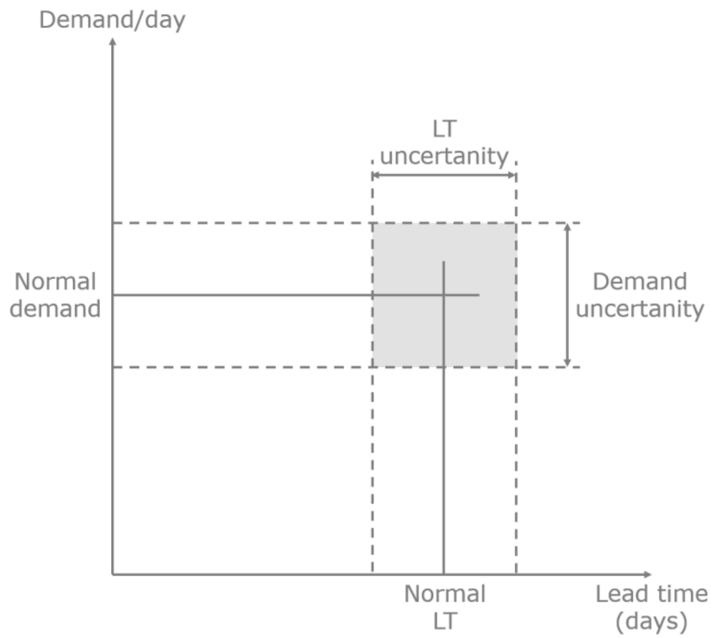

Figure 9. Demand during lead time. (Oskarsson et al. 2013, p.241)

3.2.1 Service Level

Axsäter (2006, p.94) presents three definitions of service level:

$$S_1 = probability\ of\ no\ stockout\ per\ order\ cycle \tag{1}$$

$$S_2 = \text{fill rate} = fraction\ of\ demand\ that\ can\ be\ satisfied\ immediately\ from\ stock\ on\ hand \tag{2}$$

$$S_3 = \text{ready rate} = fraction\ of\ time\ with\ positive\ stock\ on\ hand \tag{3}$$

The first definition can be interpreted as the probability of an order arriving before the stock on hand has run out. It is easy to use, but unfortunately disregards batch sizes. Large batches may make the service level measurement obsolete since a large batch size covering a long period, will cover the demand most of the time, despite a low S_1. The other definitions: fill rate and service rate, gives a better picture of the customer service but are also more complex in determining the reorder point. A higher service level generally results in a higher safety stock.

When dimensioning the safety stock it is important to understand how a change in service level may affect available resources and cost of capital. The marginal effect of a service level change might have a big impact on current stock levels, while only giving a slight change in service level. (Mattson 2011)

3.2.2 Demand Pattern

Demand patterns are often divided into five main components: trend (T), seasonality (S), cycle (C), level (L) and randomness (R), as can be seen in Figure 10. Trend is the gradual increase or decrease of demand. Seasonality is a pattern of shifts in demand, which occur on a yearly basis. Cycle is a pattern that returns every few years, often connected to the economic cycle. The level is the average demand over time, which can be found when clearing the trend, seasonality and cycle. Randomness cannot be explained or predicted but still needs to be expected. Together, these components can be combined in two main models: a multiplicative one (Olhager 2013, pp.106–107):

$$D = T * S * C * L * R \tag{4}$$

Or an additive one:

$$D = T + S + C + L + R \tag{5}$$

There are several ways to forecast demand. One of the simpler ones is the moving average, which is an average of the last N periods:

$$x_{t,\tau} = \hat{a}_t = \frac{(x_t + x_{t-1} + x_{t-2} + \cdots + x_{t-N+1})}{N} \tag{6}$$

Where α is the forecasted demand for the period and x is the demand for the previous periods. The size of N depends on how slowly α is expected to change. If α varies slowly, but with high deviations, a larger N value should be used, compared to a rapidly varying α with low deviations (Axsäter 2006).

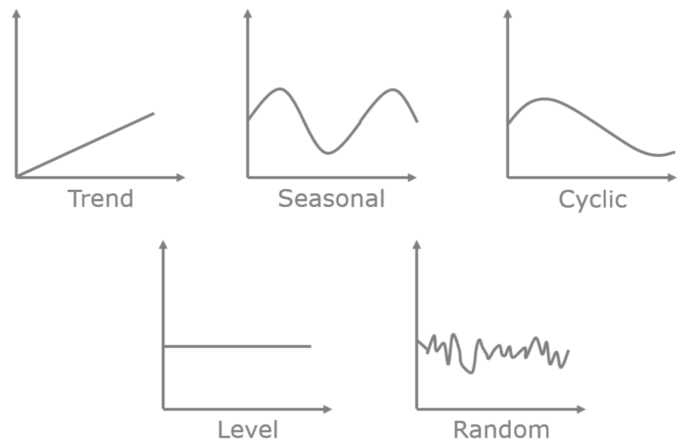

Figure 10. Demand patterns.

Exponential smoothing is very similar to the moving average, but a smoothing constant α is introduced. With the smoothing constant, exponential smoothing can provide a combination of the previous forecast and the latest demand. This results in:

$$\hat{x}_{t,\tau} = \hat{a}_t = (1-\alpha)\hat{a}_{t-1} + \alpha x_t \text{ , } for\ 0 < \alpha < 1 \tag{7}$$

Products that experience radically different demand during various seasons or time periods are affected by seasonality. This could be, for example, warmer clothing during the winter or that pizza sales are higher on Fridays than Wednesdays (Olhager 2013, p.106). If an average demand is used to calculate reorder points or safety stock, it might lead to an excessive stock during low season and stockouts during the high seasons (Chopra & Meindl 2012, pp.197–199). Therefore, there is a need for either manual updates of the safety stock calculations, or a dynamic method that can re-adjust the safety stock depending on the season. If the product has been sold for several seasons, previous data can be used to anticipate future changes in demand, and thereby adapt the safety stock accordingly.

3.2.3 Order Policy

Reordering can be done either continuously or periodically. The difference between the two is that for continually reordering, the order is placed at the same time as the reorder point is reached. For the other option, periodical reordering has certain set times, order times, where orders are placed. If the stock is above the reorder point at the order time, an order will not be placed. This implies that a larger safety stock is needed if periodical review is applied, since the stock may go below the reorder point just after an order time has passed. Moreover, longer periods also requires a higher safety stock (Axsäter 2006, p.47).

There are two common ordering policies for single echelon systems, i.e. systems with only one inventory point: the (R, Q) and the (s, S) policy. The (R, Q) policy always orders the same amount, Q, when the reorder point, R, is reached. The (s, S) always orders up to a certain level, S, when the reorder point, s, is reached. A graphical representation of (R, Q) and (s, S) order policy can be seen in Figure 11 (Axsäter 2006, pp.48–50).

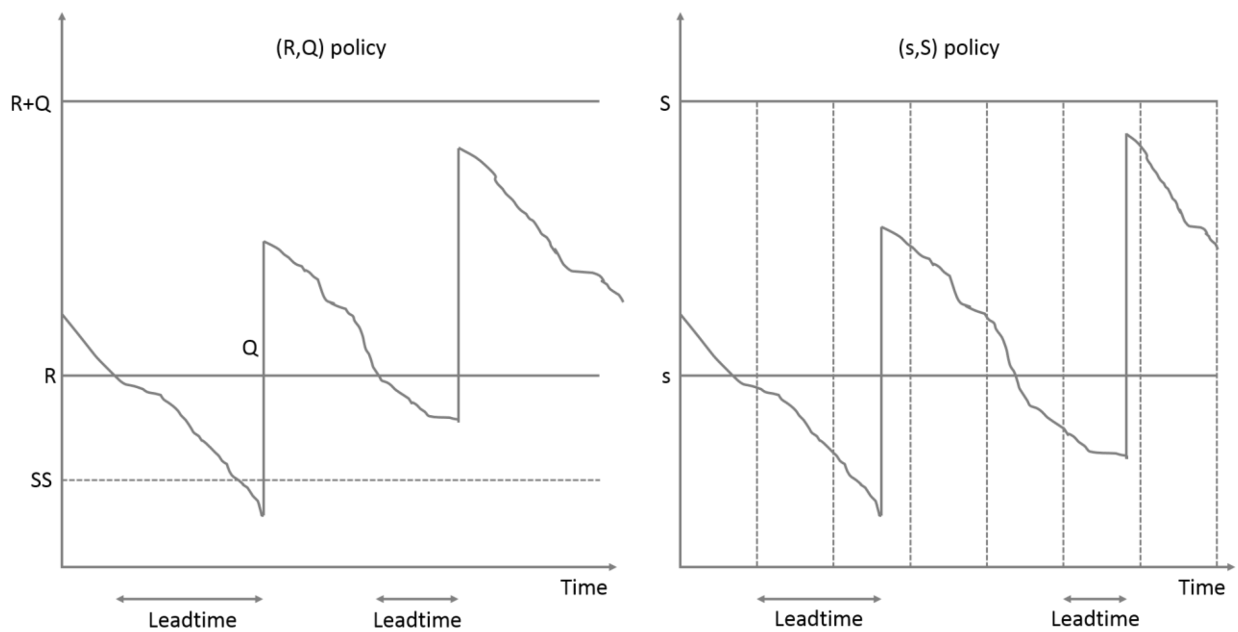

Figure 11. Continuously (R, Q) and periodically (s, S) policy. (Axsäter 2006, pp.48–50)

In Figure 11, it is clear that safety stock is necessary to cover orders when the lead time demand is bigger than expected. The reorder point can be defined as (Olhager 2013, pp.301–302):

$$RP = SS + D * L \tag{8}$$

$Where,$
$RP = Reorder\ Point$
$D = Demand\ per\ time\ unit$
$L = Lead\ time$

3.2.4 Lead Times

Uncertainties in the demand during the lead time is one reason for the need of safety stock. Both demand and lead time vary, and therefore the expected lead time and demand is necessary, in addition to the variance of them both. For high demand components, a normal distribution can be assumed. For low demand articles, a Poisson distribution is more suitable (Axsäter 2006, pp.77–78):

$$P(k) = \frac{(\lambda t)^k}{k!} e^{-\lambda t}, k = 0,1,2 \ldots \tag{9}$$

$$\begin{aligned} &Where, \\ &\lambda = intensity \\ &k = number\ of\ orders\ in\ a\ time\ interval \end{aligned}$$

A Poisson distribution should be used if the following criteria are met (Axsäter 1991, p.67):

$$E(X) < 10\ and\ 0.8\sqrt{E(X)} < \sigma_X < 1.2\sqrt{E(X)} \tag{10}$$

For non-constant demand there is also an addition to the exponential smoothing with the parameter b that is an estimation of the trend.

$$\hat{a}_t = (1-\alpha)\left(\hat{a}_{t-1} + \hat{b}_{t-1}\right) + \alpha x_t \tag{11}$$

$$\hat{b}_t = (1-\beta)\hat{b}_{t-1} + \beta(\hat{a}_t - \hat{a}_{t-1}), \qquad where\ 0 < \beta < 1 \tag{12}$$

The forecast for period t+k, is obtained by (Axsäter 2006, pp.16–17):

$$\hat{x}_{t,t+k} = \hat{a}_t + k\hat{b}_t \tag{13}$$

3.2.5 Component Commonality

The degree of component standardization affects the amount of stock needed. When the number of distinct components in manufacturing increases, the total amount of safety stock also requires an increase. Collier (1982) defines the commonality index as:

$$Degree\ of\ commonality\ index\ (C) = \frac{\sum_{j=1}^{d} \theta_j}{d}, 1 \le C \le \beta \tag{14}$$

$$\begin{aligned} &Where, \\ &\theta_j \\ &= the\ number\ of\ immediate\ parents\ component\ j\ has\ over\ a\ set\ of\ end\ items \\ &d = the\ total\ number\ of\ distinct\ components\ in\ the\ set\ of\ end\ items \\ &\beta = \sum_{j=1}^{d} \theta_j = the\ total\ number\ of\ immediate\ parents\ for\ all \\ &distinct\ component\ parts\ over\ a\ set\ of\ end\ items\ or\ product\ structure\ level \end{aligned}$$

The degree of commonality shows the average number of common parent items for the average component. The ideal safety stock in the warehouse for a standardized component, c, which replaces d number of unique components, is given by (Collier 1982):

$$S_c = \frac{1}{\sqrt{C}} * \sum_{j=1}^{d} S_j \tag{15}$$

$Where,$
$S_c = Aggregated\ safety\ stock\ for\ the\ common\ component\ part\ which\ replaces\ d\ items$
$S_j = Safety\ stock\ for\ item\ j$
$d = Number\ of\ items\ replaced\ by\ the\ common\ component$

Simulations performed by Collier (1982) showed that increasing the commonality from 1 to 2.67 can increase the service level from 80% to 91.5%, or lower the total safety stock, ceteris paribus. This is due to that the demand of a component that exists in more than one product is the aggregated demand for all those products, i.e. the buffer becomes (Baker 1985):

$$SS = k_\beta(\sigma_1^2 + \sigma_2^2 + \sigma_3^2)^{1/2} \tag{16}$$

However, there is a cost connected to increasing component commonality. For a component to be used in products, the flexibility of the component needs to increase. Thus, the cost of the component typically increases as the commonality increase. This leads to a tradeoff between component cost and safety stock inventory when deciding a level of component commonality. (Chopra & Meindl 2012, pp.350–351)

3.2.6 Cost of Stock

There is a cost of capital for all stock, which mainly originates from the cost of purchase. However, storage, wages, equipment for material handling, and obsolescence are also factors affecting the cost. During the production and when the components move further in the supply chain, their value increases and the cost to hold it in stock will also increase, i.e. closer to the end consumer the holding cost gets higher (Olhager 2013, pp.33–34). Therefore, chosen safety stock levels and the internal rate of return affect the cost of stock.

3.2.7 Product Quality

Products received from suppliers could reach a non-satisfactory level for several reasons, for example production quality problems or the way they have been handled during transport (Chopra & Meindl 2012, pp.66–68). To lower this, quality inspections at receiving can be made. Moreover, handling in the own facilities during storage or production can cause product waste. To cope with this, extra stock could be held, either finished goods stock or direct material stock. If there is a known level of scrap, another solution is to order more material than what is demanded by production.

3.3 Safety Stock Calculation Methods

There are four main categories of safety stock dimensioning methods. The first one is the assessment method, where safety stock is based on past experience or intuition. The second method is called the proportion method where safety stock calculations are set in proportion to the mean demand, for example number of days the demand is covered by safety stock. However, demand variation is not considered.

Thirdly, the statistical model takes demand distribution and service level into consideration. Finally, the fourth method called the shortage cost method is also based on statistical distributions, but tries to minimize shortage cost or tied up stock. (Mattson 2011)

3.3.1 Calculating Safety Stock

The required safety stock is highly dependent on the forecast errors. Standard deviation is the most common way to describe any variations around the mean.

$$\sigma = \sqrt{E(X-m)^2} \tag{17}$$

When working with forecast errors, it is uncommon to use standard deviation directly. Instead, Mean Absolute Deviation (MAD) is estimated, which is the expected value of the absolute deviation from the mean.

$$MAD = E|X-m| \tag{18}$$

MAD was originally used because it made calculations easier, and even though it is not a problem to use standard deviation or variation today, MAD is still commonly used by most forecasting systems. When forecast errors are assumed to be normally distributed, the relation between MAD and standard deviation is as follows: (Axsäter 2006, pp.29–30)

$$\sigma = \sqrt{\frac{\pi}{2}}MAD \approx 1.25MAD \tag{19}$$

When calculating safety stock, it is appropriate to consider the standard deviation over the lead time rather than for just one period of time, this is denoted as σ'. Based on the lead time deviation and a service factor, which is dependent on the service level, the safety stock can be calculated as:

$$SS = k\sigma' \tag{20}$$

Where k is the safety factor, dependent on the service level. In Table 3 a few different service levels and their corresponding safety factors are displayed. (Axsäter 2006, p.96)

Table 3. Safety factors for different values of service level S1. (Axsäter 2006, p.97)

Service level S_1	0.75	0.80	0.85	0.90	0.95	0.99
Safety factor k	0.67	0.84	1.04	1.28	1.64	2.33

The majority of safety stock methods can, on a high level, be described as in Figure 12 (Peterson & Silver 1979, p.256).

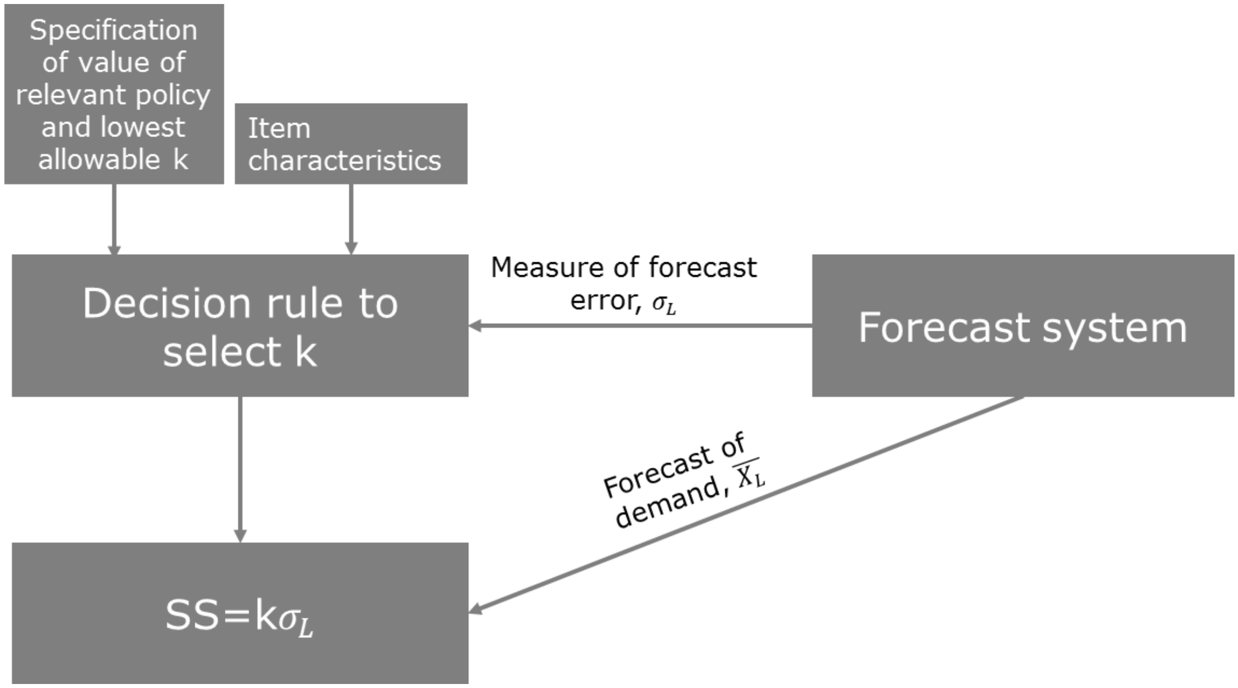

Figure 12. Overview of k-selection in safety stock methods (Peterson & Silver 1979, p.256).

3.3.2 Comparing Methods for Calculating Safety Stock

Schmidt et al. (2012) and Mattson (2011) uses simulation to compare different methods for calculating safety stock. These methods will be presented below followed by the result of the comparison.

Schmidt

The first method is often referred to as the standard method, which determines safety stock based on the service level:

$$SSL = SF(SL) * \sigma_D \tag{21}$$

$$\begin{aligned}&Where,\\&SSL = Safety\ stock\ level\ [units]\\&SF = Safety\ factor\ depending\ on\ service\ level\\&SL = Service\ level\\&D = Standard\ deviation\ of\ demand\ \left[\frac{units}{SCD}\right]; SCD = shop\ calendar\ day\end{aligned}$$

The second method is an extension of the first which also considers replenishment time. This is the same method that Axsäter (2006, p.96) suggests, as presented above, with $\sigma' = \sqrt{\sigma_D * TRP}$:

$$SSL = SF(SL) * \sigma_D * \sqrt{TRP} \tag{22}$$

$$\begin{aligned}&Where,\\&TRP = Replenishment\ time\ [SCD]\end{aligned}$$

Method three is a similar method suggested by Alicke (2005), which also uses the safety factor, but uses a standard deviation of forecast error derived from historical forecast data, instead of the historical standard deviation of demand:

$$SSL = SF(SL) * \sigma_F * \sqrt{TRP} \tag{23}$$

$Where,$

$\sigma_F = Standard\ deviation\ of\ the\ forecast\ error\ of\ the\ demand\ during\ TRP\ [\frac{Units}{SCD}]$

In method four, Hermann (2011) extends this approach by using the so-called “undershoot”. Which refers to the problem when stock might already be below the order point immediately before an order is triggered.

$$SSL = SF(SL)\sqrt{Var(U) + TRP * \sigma_D^2} \tag{24}$$

$Where,$

$Var(U) = Variance\ of\ the\ undershoot\ [\frac{units^2}{SCD^2}]$

Methods five through nine use the aforementioned concepts and extends them with a stochastic replenishment time.

Method five:

$$SSL = SF(SL) * \sqrt{TRP * \sigma_D^2 + D^2 * \sigma_{TRP}^2} \tag{25}$$

$Where,$

$D = Demand\ per\ period\ \left[\frac{units}{SCD}\right]$

$\sigma_{TRP} = Standard\ deviation\ of\ replenishment\ time\ [SCD]$

Similarly, to how method four was an extension of method three, method six is an extension of method five by Herrmann (2011) that also considers the undershoot:

$$SSL = SF(SL) * \sqrt{Var(U) + TRP * \sigma_D^2 + D^2 * \sigma_{TRP}^2} \tag{26}$$

Gudehus (2007) applies method five with an adaptive service level factor which considers that only disruptions during the replenishment cycle can lead to a lack of delivery capability. If a mean delivery capability is to be reached over the period between the inputs of two orders, a smaller value than the required delivery capability is good enough for the service level during the critical replenishment time phase.

$$SSL = SF\left(1 - \frac{(1 - SL) * QRP}{TPR * D}\right) * \sqrt{TRP * \sigma_N^2 + D^2 * \sigma_{TRP}^2}$$
$$\forall\ QRP < TRP * D \tag{27}$$

$Where,$

$QRP = Replenishment\ quantity\ [units]$

In method eight, Gudehus (2007) adjusts the seventh method further by applying simple exponential smoothing. This should consider the dynamics of the parameters:

$$SSL = SF\left(1 - \frac{(1-\alpha\ ) * QRP}{TPR(t) * D(t)}\right) * \sqrt{TRP(t) * \sigma(t)_N^2 + D(t)^2 * \sigma(t)_{TRP}^2}$$
$$\forall\ QRP < TRP * D \qquad (28)$$

$Where,$
$TRP(t) = Replenishment\ time\ forecasted\ for\ period\ t\ [SCD]$
$D(t) = Mean\ demand\ per\ period\ forecasted\ for\ period\ t\ [SCD]$
$\sigma_{N(t)} = Standard\ deviation\ of\ demand\ during\ replenishment\ time$
$forecasted\ for\ period\ t\ \left[\frac{units}{SCD}\right]$
$\sigma_{TRP(t)} = Standard\ deviation\ of\ replenishment\ time\ forecasted\ for\ period\ t\ [SCD]$

Method nine avoids using a specific statistical distribution and considers any extreme values beyond the mean and standard deviation. It determines the safety stock for a target service level.

$$SSL = LSL_0 * (SL^2 - 1) + SSL_{100\%} * \sqrt[C]{1 - (1 - SL)^C}$$
$$\text{with, } LSL_0 = \frac{QRP}{2} \qquad (29)$$
$$\text{and, } SSL_{100\%} = \sqrt{\left(DV_{d,max}^{+} * D\right)^2 + \left((D_{max} - D) * TRP\right)^2 + \left(DV_{QRP,max}^{-}\right)^2}$$

$Where,$
$LSL_0 = Lot\ stock\ level\ [units]$
$C = C - norm\ function$
$DV_{d.max}^{+} = max\ positive\ deviation\ from\ due\ date\ [SCD]$
$D_{max} = maximum\ demand\ per\ period\ \left[\frac{units}{SCD}\right]$
$DV_{QRP,max}^{-} = max\ negative\ deviation\ in\ replenishment\ quantity\ [units]$

Method nine is based on calculating a safety stock for a target service level of 100%. The safety stock can be adjusted via the C-Norm function, if a lower service level is sought for.

Mattson

In a similar manner to Schmidt et al. (2012), Mattson (2011) also performed simulations to test five different methods for calculating safety stock.

The first method is to dimension the safety stock to cover demand over a certain number of days.

$$SSL = Number\ of\ safety\ stock\ days * Daily\ consumption \qquad (30)$$

This leads to high demand products having a higher safety stock than those with low demand. Mattson (2011) argues that this is good for the average service level since it is more affected by high volume products.

The second method is to set the safety stock as a percentage of the demand during the lead time. This is very similar to the first one, but is instead related to the length of the lead time.

$$SSL = Safety\ stock\ percentage * Lead\ time * Daily\ consumption \qquad (31)$$

The third and fourth methods that Mattson (2011) tests are almost identical to the second method tested by Schmidt et al. (2012) with some minor variations in how the service level is defined, one with S_1 and the other with S_2.

Lastly, the fifth method is based on the shortage cost method where the goal is to minimize the storage and shortage cost, based on the probability that a shortage cost does not occur during the period:

$$\Phi(k) = 1 - \frac{Price * SF * Q}{Bkg * COrd} \tag{32}$$

$$\begin{aligned}
&Where,\\
&SF = Storage\ Factor\\
&Q = Used\ order\ quantity\\
&CoS = Cost\ of\ Shortage\\
&Cord = number\ of\ Customer\ Orders\ per\ year
\end{aligned}$$

3.3.3 Simulation Results

Schmidt

The simulations made by Schmidt et al. (2012) aims to test the different methods to see what service level they achieve, and under what circumstances they are suitable to use. An exemplary evaluation of a trial series with target service level of 95 % is presented in Figure 13.

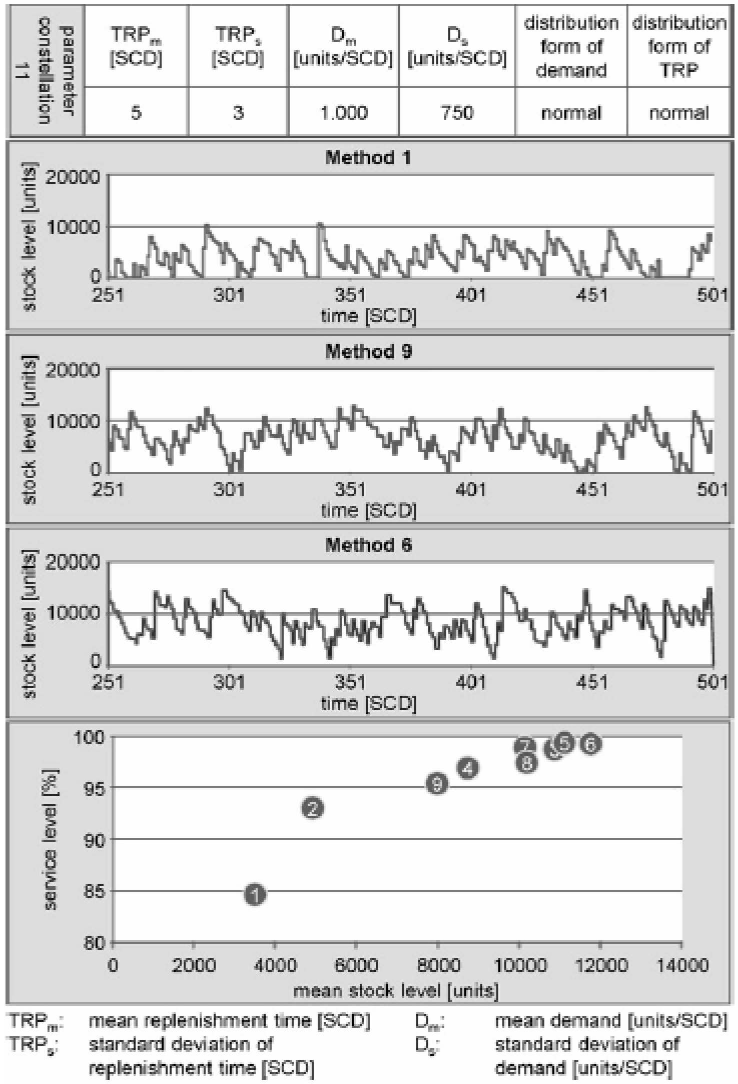

Figure 13. Exemplary evaluation of a trial series. (Schmidt et al. 2012)

As seen in Figure 13, the different methods provide quite different results. Method (1) has a low mean stock level, but does not reach a high service level. Method (2) improves the service level quite a bit, but also requires a higher mean stock level. The other methods are all above 95 % service level but vary between 8,000 and 12,000 units of mean stock level, a large increase compared to the first method. Based on these tests, it becomes clear that each method is appropriate for different situations or demand characteristics. Schmidt et al. (2012) conclude the paper with a recommendation of which methods to use in situations of different variance of demand and replenishment time, the results are shown in Figure 14.

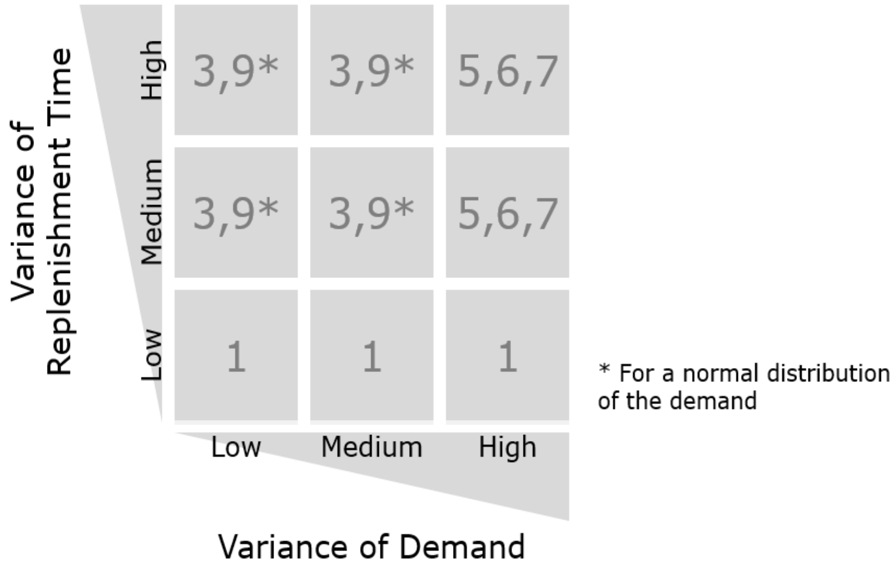

Figure 14. Preferable application area cluster of the calculation methods. (Schmidt et al. 2012)

Mattson

Mattson's (2011) simulations conclude that on the test company the shortage cost method minimizes the cost if all five methods are set to the same service level. One reason for this could be that the fifth method considers both cost of capital and cost of delays. Interestingly, the simulations show that both method one and two performs better than the third and fourth. An explanation to this is that the first and second method differentiate service levels more for different products whereas the third and fourth methods tend to set about the same level for all products.

3.4 Safety Time

Safety time, also known as safety lead time, is defined by van Kampen et al. (2010) as "the difference between the release time and the due date minus the supply lead time of the product, where supply lead time is defined as the time that is required to produce the order." Their study focused on the advantages and disadvantages of safety lead time and safety stock in a system of multiple products with variable supply and uncertainty in demand information. The results of the case study showed that a safety lead time is more effective for supply variability. When dealing with uncertainty in demand information, safety stock was preferred in most cases.

In situations combining both supply and demand uncertainties, the more efficient strategy was a safety time when compared to an equivalent level of safety stock. However, when demand uncertainty is high, using a safety lead time leads to higher inventory levels and a higher spread in inventory storage needs, compared to an equivalent level of safety stock. (van Kampen et al. 2010)

Mattsson presents three main methods for setting the safety time. Estimated safety time is the most basic version that is completely based on personal experience and knowledge. The method is very dependent on the person deciding the safety time and thus becomes difficult to apply in a systematic way across all products. Another drawback is the large amount of time and effort required for updating and adjusting the safety times as circumstances change. This method is mainly useful when certain data is missing, e.g. for suppliers which are seldom used. (Mattsson n.d., chap.E31)

The second method is a development of the estimated safety time. Safety time as a percentage of lead time uses the lead time as a base and then sets the safety time in proportion. The percentage is estimated based on intuition or personal experience. This method is advantageous to the estimated safety time since it is based on the lead time. It can also be easier to update and adjust if the percentage is set for a product group instead of individually, e.g. per supplier, category of uncertainty or volume. (Mattsson n.d., chap.E32)

The third method is a safety time based on service level for delivery point, which refers to the delivery point that is expected based on the lead time in the ERP system. Uncertainty contains both late deliveries, but also that the supplier might accept and confirm a delivery point which is later than the expected delivery point. If the demand follows a normal distribution, the safety time is calculated as:

$$ST = k * \sigma_{LT} \tag{33}$$

$$Where,$$
$$\sigma_{LT} = standard\ deviation\ of\ lead\ time\ variations$$

By using a desired service level as a basis in the calculation, the calculations are often superior to the manual methods, since it is near impossible to manually choose a safety time which represents a desired service level. Since the method is based on objective calculations and data, the results are also easier to complete in automatic calculations and easier to follow up and adjust. However, the method requires information about lead time variations, or an appropriate way of estimating them. (Mattsson n.d., chap.E33)

3.5 Safety Stock under Material Requirements Planning

Peterson and Silver (1979, pp.458–459) argue that a reorder point system, as described in 3.2.3, has several weaknesses in a manufacturing setting. Firstly, there is no need to estimate component requirement, since once the production plan is set the component requirement will follow. Secondly, in production, the demand is not smooth, which makes it hard to set safety stock. Lastly, the demand for a component should not be seen as independent, since if one of all components of a product is out of stock, the production will stop. Therefore, the authors suggest Material Requirements Planning.

For multi echelon systems, focusing on a system of inventory points, Material Requirements Planning is another tool for inventory control. Material Requirements Planning seek to overcome the flaws of replenishment systems for manufacturers, by using the demand dependency on components and raw material. By coordinating the demand for several components, the chances of production stops due to lack of one out of several components decreases (Peterson & Silver 1979, p.465).

The finished goods are broken down in bill of materials, making it possible to plan demand on a direct material basis based on forecasts and master production schedules. With the master production plan, it is known when the material is needed (Peterson & Silver 1979, pp.465–467). With this, it is possible to calculate reordering points with the aim to have the lowest possible stock on hand for a set service level.

By starting with the requirement of the final product for each product and period, it is possible to derive order points for the required material, given certain lead times and safety stock requirements (Axsäter 2006, pp.204–208).

Peterson and Silver (1979, p.474) argue that with material requirements planning, there should not be any need for safety stock since safety stocks are not appropriate in a dependent demand situation. Shortages should instead be avoided by production adjustments. However, in reality there is often a need for safety stock due to forecast errors (Baker 1985). Yano and Carlson (1987) determined four elements that are important to consider for placing safety stock at component level rather than at finished goods. They conclude that safety stock should be kept at component level when: component holding cost is significantly lower than for finished goods, set up times are longer for components than finished product assembly, fill rates are high, and including components availability are high too.

Etienne (1987) begins by stating that the philosophy of zero safety stock or safety time is difficult in reality due to difficulties in removing all uncertainties. The basis is two dimensions of uncertainties: the nature of the uncertainty, i.e. variations in timing or in quantities, and the source of uncertainties, i.e. from demand or supply phenomena. The article focuses on comparing buffers based on safety stock and safety time. Safety time is added by always ordering earlier than the material is needed, e.g. ordering to receive in four weeks when it is needed in six weeks.

According to simulations by Whybark and Williams (1976), the safety time strategy is preferred when dealing with uncertainty in timing. Safety stock is preferred for quantity uncertainty. However, the results were indifferent between the source of uncertainty, supply or demand.

Etienne (1987) seeks to expand this model to develop a decision model for choosing between the two methods. With the conclusion that no buffering strategy is superior in every situation. For situations with timing uncertainty, a safety time is preferable when the material schedule is sparse. A second factor to consider is the target service level, where low service levels favor safety time, while safety stock is appropriate for high service levels. However, when considering situations of quantity uncertainty, the safety time is deemed useless and safety stock should be applied instead.

Another aspect to consider is where to put the safety stock. Lagodimos and Anderson (1993) concluded that several independent factors such as network configuration and demand variability matters. However, the simulations confirmed that for simple, serial networks safety stock should be focused to the upper echelon, but more research is needed to see if it can be applied to more general networks.

3.6 Product Classification

Articles can be classified into different categories by using certain factors as ranking. The aim is to find similarities and differences between products. The rankings can be used for several purposes: inventory control, forecasting and analysis of the product range are three examples.

Volume Value

The volume value of an article is the yearly consumption multiplied by the article value. It is common that in a company, a small number of articles contributes to a large part of the yearly revenue. This also leads to a corresponding statement for the rest of the articles. A large number of articles contribute to a small part of the yearly revenue. This relation is often called the 80/20 rule. 20 % of the articles contribute to 80 % of the revenue, and 80 % of the articles contribute to 20 % of the revenue. This kind of analysis can be the basis of an ABC-analysis, which is used to categorize articles into a number of classes, e.g. A, B, and C. The different classes may then be treated differently in other contexts. (Olhager 2013, pp.36–40)

Cover Time

Cover time is the time the current stock can be expected to last. Using cover time instead of the number of articles in stock makes it easier to interpret the numbers and take necessary actions.

Demand Frequency

While two articles can have identical volume values, the underlying pattern of demand may be completely different. One could be ordered in small but frequent orders, while the other could have large but infrequent orders. Thus, the two articles would benefit from being treated differently. A classification that combines the volume value and the demand frequency may be appropriate in these cases. Figure 15 provides an example of this combination.

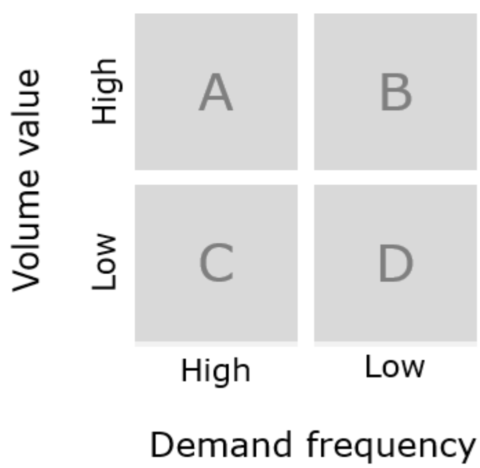

Figure 15. Article classification with regard to volume value and demand frequency. (Olhager 2013, p.40)

Oskarsson et al. (2013, p.255) describe the steps of the classification process as:

1. Choose classification criteria and calculate that for each article
2. Rank the articles from high to low, based on the chosen criteria
3. Calculate each articles share of the whole, based on the chosen criteria
4. Calculate the accumulated share
5. Calculate each articles share of the total number of articles
6. Calculate the accumulated share
7. Choose suitable classifications for each product

With an article classification it becomes easier to control the articles properly. Instead of making choices on an article basis, some choices can be made for the whole group and the articles can be moved from one group to another when needed. However, it is still important to understand why an article has a certain set of attributes and demand pattern. (Olhager 2013, pp.36–40)

3.7 Simulation

Defining if a simulation is good can be hard when there are no reference points. The validation criteria's of simulations has been discussed by Lenhard et al. (2007, chap.1) and how to know if a simulation models reality. Lenhard et al. argue that a simulation model has to be structural valid, i.e. it has to structurally represent the system it is investigating. A model could be structured by implementing and imitating the same rules as of the real world it tries to model. This could be easier said than done, and many models are not completely replicating all rules, so there will always be discrepancies between the real world and the modeled world.

The entities of a model and simulation are described by Zeigler et al. (2000, pp.25–29) in Figure 16. They define the source system as the source of data, either artificial or from a real source, i.e. the environment that the model is based upon. The data collected is stored in the behavior database and acts as the data foundation of the model and simulation. Surrounding the data is the experimental frame, which is a specification of the conditions for the system of experimentation. This, for example, could be the variables that are of interest for the study. Once this is defined, a model can be constructed to generate data in the desired way, based on the data and variables obtained in behavior database and the experimental frame. Robinson (2015) explores different models and argues that there are benefits of using conceptual models. A conceptual models aim is not to include all available information in a model, but rather choosing what the model should focus on, giving a simplified representation of the real world in the simulation model. The conceptual model is used to describe objectives, inputs, outputs, and content of the computer model, and works as a communication tool to get stakeholders on board. Finally, the simulation is the computational part that generates outcomes based on the model.

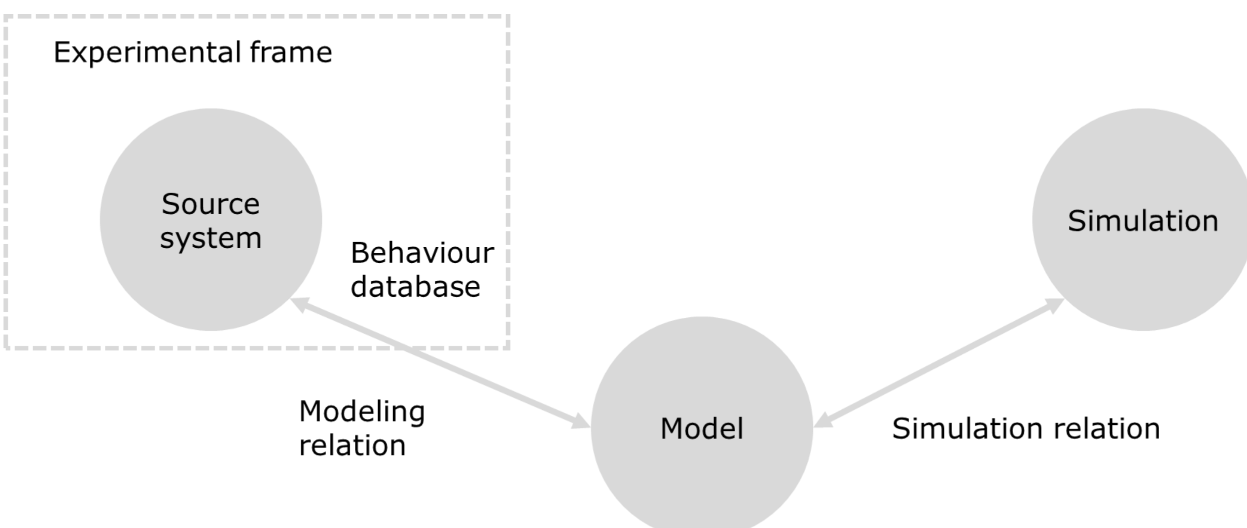

Figure 16. The basic entities on modeling and simulation, and their relationships. (Zeigler et al. 2000, p.26)

Jönsson (1983, p.39) designed a model for simulation of inventory control systems, see Figure 17. The uncertainties in the model are based on lead time and demand variations, which can be coped with through either safety time or safety stock.

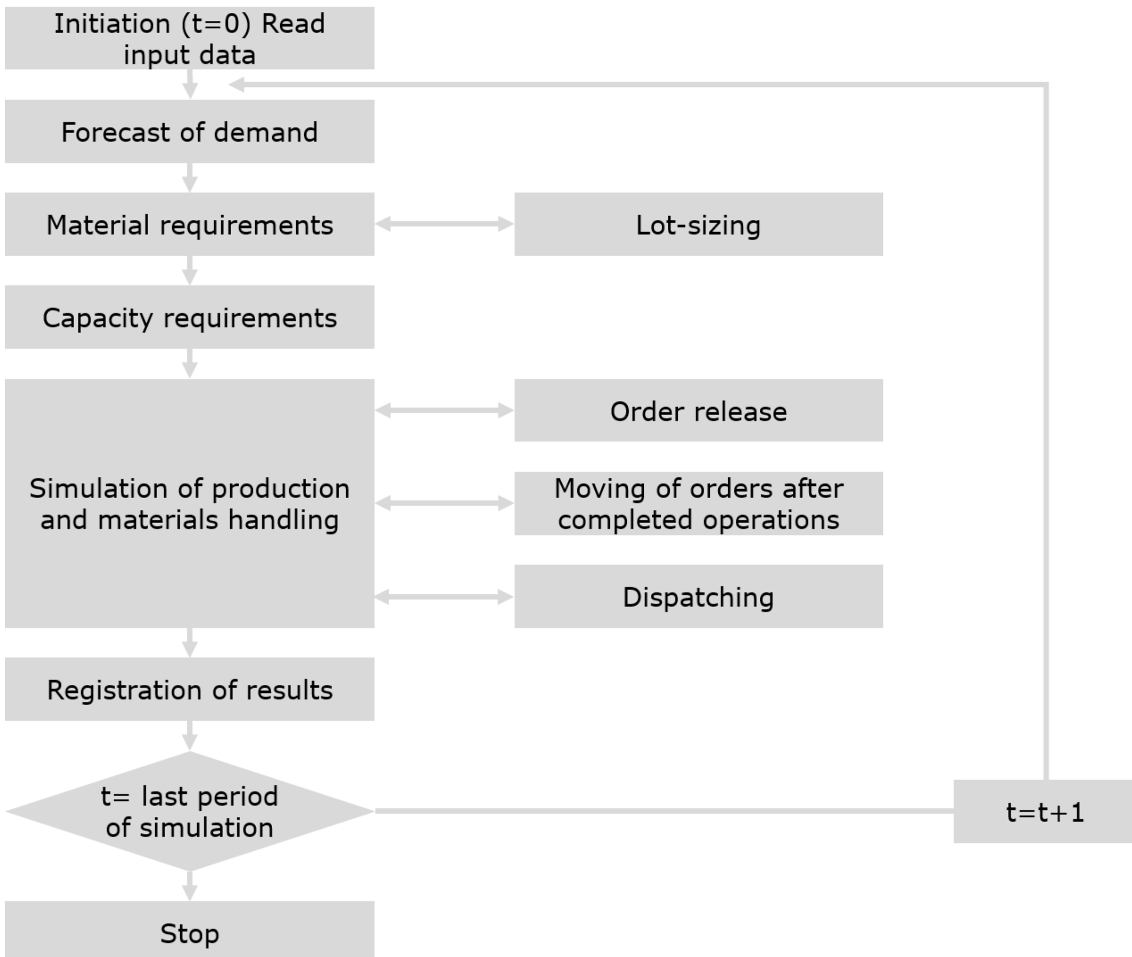

Figure 17. Production and inventory control simulator. (Jönsson 1983, p.39)

Safety stocks are affected by several variables in a simulation, and many of them are hard to determine. Commonly, inventory scenarios are compared under the constraint of a target customer service level (Køhler Gudum & de Kok 2002). Olhager and Persson (2006) show the interdependencies of production control system parameters in Figure 18. Customer service policy, demand variance, and average demand are all dependent on the customer and what has been agreed. The safety stock depends on how much the demand varies, and especially how predictable the variations are. By receiving forecast from the customer, the amount of safety stock can be decreased, if the forecasts are accurate (Persson et al. 2017).

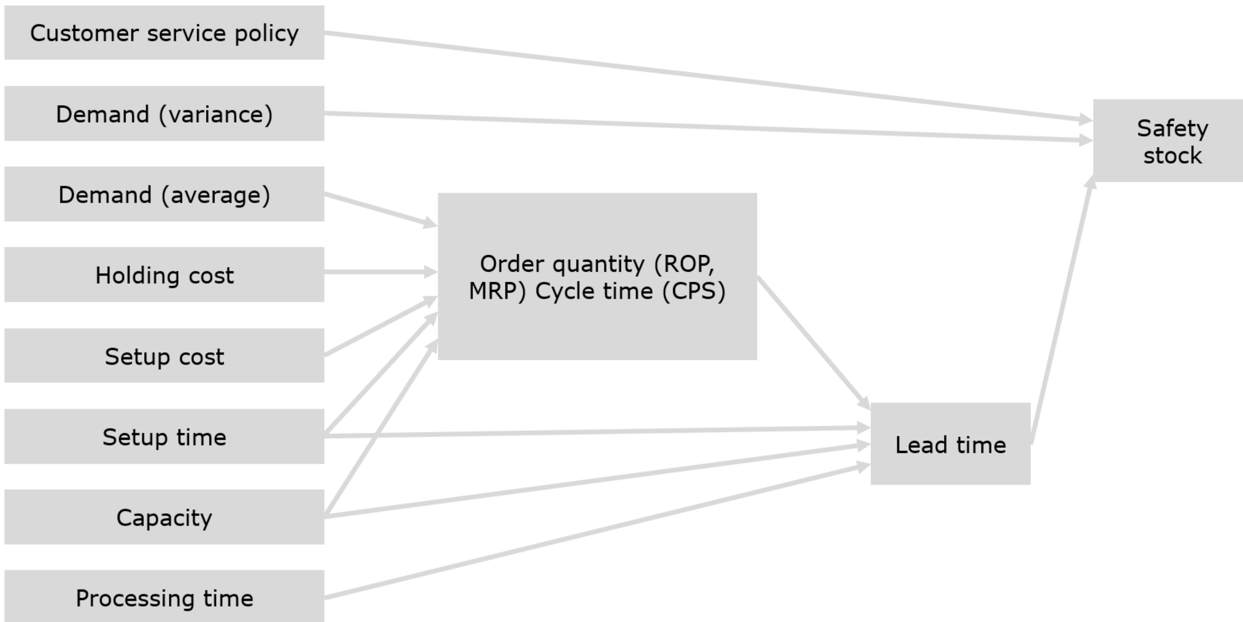

Figure 18. Interdependencies between production and inventory control system parameters. (Olhager & Persson 2006)

3.8 Pilot Study

The definition of a pilot is not fully settled in the scientific community. According to Arnold et al. (2009) there are three main types of pilot projects:

- Pilot work - any background research that informs a future study
- Pilot study - studies with a specific hypothesis, objective, and methodology
- Pilot trial - a stand-alone pilot study that includes a randomization procedure

In the study by Thabane et al. (2010) the overall purpose of a pilot study is identified as a feasibility study meant to lead the plan for a large-scale investigation. They describe the reason for a pilot with an African proverb *"You never test the depth of a river with both feet"*, which can be translated into a need to test the viability, and possibly avoid bad consequences.

However, Arian et al. (2010) suggest that there should be a distinction between 'pilot' and 'feasibility' studies. Studies labeled 'feasibility' used a more flexible methodology compared to the 'pilot' studies with more thorough methodological components. Additional differences observed were that pilot studies often concluded with inconclusive results and intentions of continuing with a larger test, while the feasibility studies often did not express such intentions. However, Arian et al. (2010) note that fewer studies than expected are actually followed by a larger study. The main reasons were that the pilot showed a significant result or that the results were unfavorable.

Possible benefits of pilot studies include, according to Brooks et al. (2016), improved likelihood of success for the main study; increased knowledge of the researchers; prepare and refresh interview and observation techniques; assess appropriateness of suggested tools; evaluate data analysis procedures to enable any necessary adjustments; and give an estimated time and cost for the project.

However, it is important to remember that there are also limitations of pilot studies. According to van Teijlingen and Hundley (2002) potential issues, include inaccurate decisions based on the pilot data, future studies having their data contaminated from the pilot study, and issues connected to project funding. Sampson (2004) mentions another risk in that many researchers stop the pilot too quickly after limited reflection. This can lead to a loss of potential gains that require a proper analysis to reach.

3.9 Literature Summary

Figure 19 provides an overview of the conducted literature review and also the basis for the continued investigation. The research questions are covered by different parts of the literature review, with RQ1 as a base and prerequisite for RQ2 and RQ3.

The four main factors affecting the safety stock levels identified in the literature were: service level, demand pattern, supplier lead times, and product commonality. The demand pattern and lead times are external factors, while service level and product commonality are internal factors.

The effect on safety stock depends on all the factors above, but also on which method you are using to determine safety stock. Additionally, the adoption of MRP might lead to some necessary adjustments to the safety stock method. Finally, the order policy and the use of product classification can be additional factors to consider when creating a framework for safety stock.

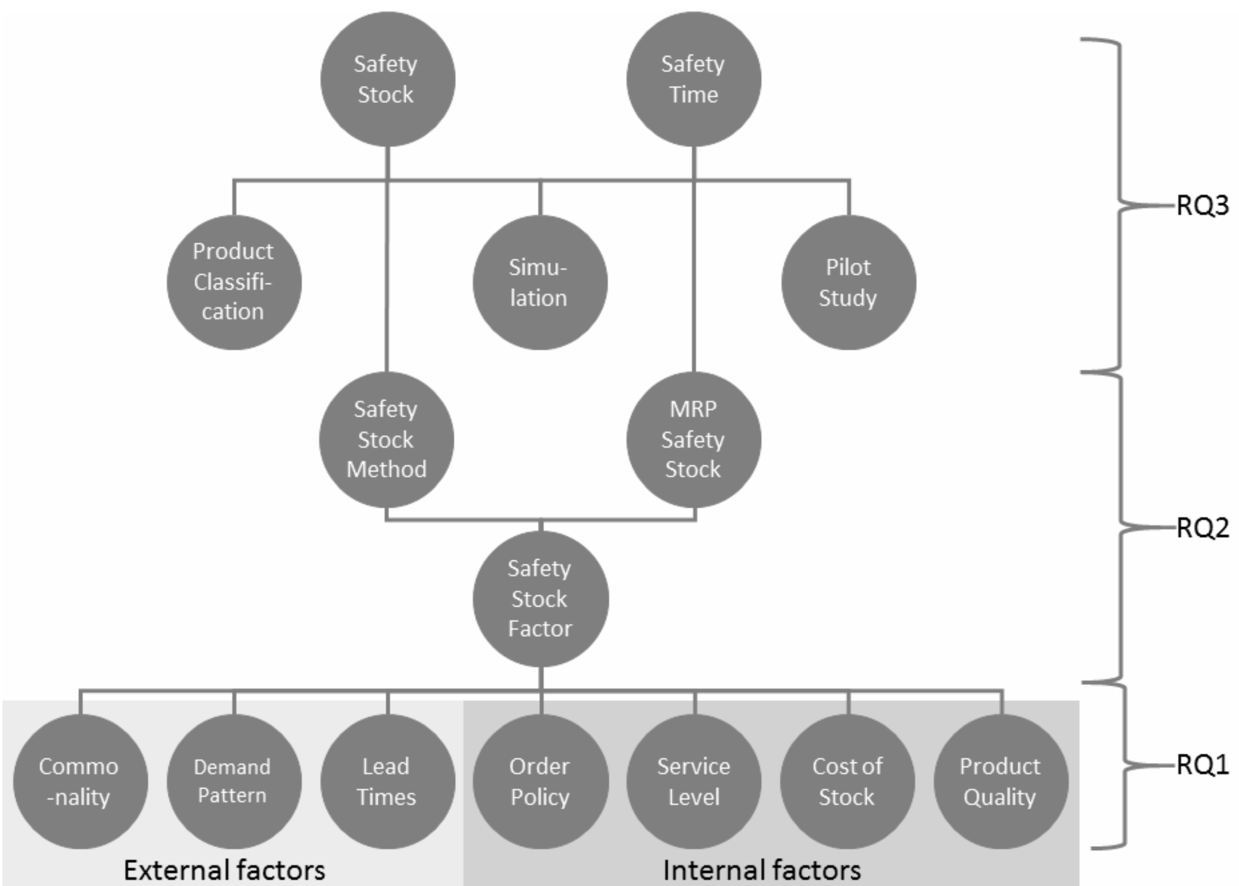

Figure 19. Summary of the conducted literature review.

4 Case Description

The reader will be introduced to the case company, IKEA Industry; the case site, Lubawa, Poland; and the way safety stock is currently handled. The IKEA Industry's view on stock, an overview of the supply chain and their ERP-system will also be covered.

4.1 IKEA Industry

The history of IKEA Industry began a few years ago when some of IKEA's wholly owned suppliers were integrated into one company, IKEA Industry. When IKEA in 2010 decided on a goal of doubling the revenue until 2020, they realized that a standardization within all parts of the value chain was needed to reach this goal. Thus, IKEA Industry was formed as part of the initiative to reduce supplier costs and secure supply. IKEA Industry is the in-house furniture production of IKEA and also the largest supplier of all of IKEA's 1,000 suppliers, corresponding to 15% of all IKEA sales. IKEA Industry now consists of 40 facilities, mainly in Europe, which focuses entirely on products made from wood, such as the wardrobe PAX and the table LISABO. (IKEA Industry 2018)

4.2 IKEA Industry Supply Chain

One interesting aspect of IKEA Industry's supply chain is that IKEA Industry owns a large part of it. This includes sawmills, component factories, furniture factories, and all the way to a finished product, ready to be delivered to the IKEA warehouses or retail stores. This means that some factories are suppliers to other IKEA Industry factories. The main advantage of this setup is that information sharing is well implemented throughout the supply chain. This could help to reduce the bullwhip effect and increase forecast accuracy. The IKEA Industry supply chain is illustrated in Figure 20.

Information sharing starts with IKEA making a demand plan based on their retail sales forecast. The demand plan is then used as a basis to create a need plan "SPI", covering the next 52 weeks, which is shared in an updated version with IKEA Industry every week. From the SPI, IKEA Industry creates a master plan for the upcoming 26 weeks, and a production plan for the next 6 weeks. With MRP, the production plan is developed into a supply plan with proposed purchase orders and delivery orders for each material and component. The goal of this setup is to allow fast analysis of forecast changes and how these will affect key suppliers.

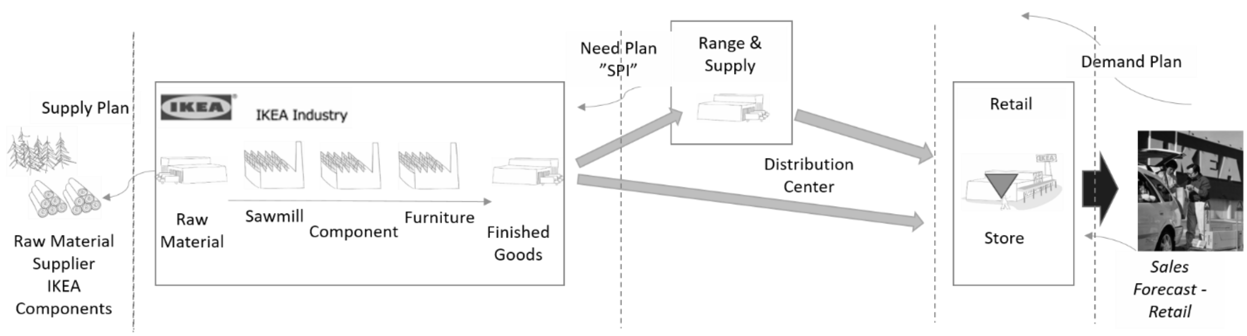

Figure 20. The IKEA Industry Supply Chain. (Borges et. Al. 2018)

4.3 Current Way of Working with Inventory

A few years ago, an implementation project called Blueprint was initiated. Previously, all factories that are now part of IKEA Industry were working individually using their own choice of IT systems and practices. As a part of the global model, much work has been dedicated to moving towards a unified way of working, using the same IT systems and practices at all sites. Even though progress has been made, the process is still ongoing and not finished. There are still differences in how factories choose to approach certain processes and how well the new IT systems have been implemented and utilized. Thus, there are still a few different ways in which sites work with inventory. A few examples follow:

The site Paços de Ferreira in Portugal was one of the first factories to change to the new systems and practices when Blueprint was introduced. They are often referred to as one of the most well adapted factories. Currently, Paços is using the following approach when deciding safety stock: The supply planners update the safety stock at least twice per year, or every time there is a significant product mix change. In their process, considered factors include scrap and inventory deviation history, supplier performance, production plan adherence, order history and warehouse capacity. Based on these factors, the supply planners can make appropriate adjustments to the safety stock for each item.

Hultsfred is a site that gives an interesting contrast against the ordinary IKEA Industry factory. The site consists of both a board factory and a furniture factory. This result in low lead times for boards delivered from the board factory and allows for low safety stock at the furniture factory. Hultsfred furniture is also different from other sites in that it only produces 50 different article variations and uses 150 direct material articles, enabling the purchaser to keep a good overview. The factory tries to work in a very LEAN fashion with low direct material safety stocks. In reality there is often some stock of direct material that acts as a buffer due to the way of planning. Planning is made for constant full capacity production. However, even though production is much automated, or perhaps due to this situation, production never reaches these levels and some direct material is not used. Main factors used by the purchaser when deciding safety stock are: cost, lead time, lead time variation, average quality of materials, and the size of the supplier.

Lubawa is one of the largest of IKEA Industry's facilities. Having continually grown in size over the 25 years it has been operating, the site is constantly balancing the labor costs with the increasing need and efficiency gains of automation. The factory is extensive, especially when compared with Hultsfred. With production of 300 different articles and usage of approximately 2000 different direct material articles, supply planning is far too much for a single person. Therefore, the supply planners are responsible for different item groups. Still, this large number of articles leads to much work when updating the safety stocks. Moreover, the planners think differently when deciding safety stock, leading to variances between the product groups. For these reasons, an interest has been expressed in having a solution which is as smooth and automatic as possible. Currently, the safety stocks are based on the perceived importance of the material for production, and the available warehouse space. Some of the most commonly used articles have gotten large safety stocks to ensure production in the case of delivery delays. Other articles, such as packaging materials, are barely kept in stock and instead use a Just-In-Time setup due to a lack of storage space.

Currently, one of the biggest issues regarding safety stock that IKEA Industry faces, is the lack of warehouse space in connection to the different sites. Building new warehouses will be expensive and in some cases impossible due to land limitations. In many cases, direct material stock and finished goods are competing for the available storage space, and traditionally finished goods have been considered more important. With that said, there might be too much stock for some product groups at the sites, including direct material. This is because stock is considered as an asset rather than a cost. In addition, the internal rate of return is low and not widely discussed at IKEA Industry, resulting in that keeping stock is considered cheap and the incentives to reduce stock are low. However, this is about to change. The management has recently increased the focus on the cost of capital and on the total time material is spent in the supply chain. Both of these initiatives will most probably have an impact on safety stock, and stock in general. To make sure that the right amount of stock is used, a statistical approach to safety stock will be one tool to improve the processes.

In addition to the use of safety stock, many products have a safety time too. However, at Lubawa, the safety time is not used as intended by the literature. The safety time is mainly used to adjust the delivery for how long the production takes, and that all articles should arrive the Friday before a production week. Production is planned for a week but the production order is unknown at the time of order and might change, thus requiring all materials to be available at the start of the week.

4.4 Safety Stock Initiative for Finished Goods

This master thesis is not the first investigation of safety stocks conducted at IKEA Industry. At the other end of the supply chain, a framework for dimensioning safety stocks for finished goods has already been developed, but not fully implemented. The scope of the investigation was finished goods for IKEA Industry and other suppliers.

The method derived by the investigation considers three main factors: supply uncertainties, reaction time to uncertainties, and demand uncertainties. Supply uncertainties occur when fewer products are produced than what was planned, which may result in a lack of stock. The reaction time to uncertainties is mainly dependent on the frozen period, during which the production plan should not be changed. Demand uncertainties occur when ordered demand is larger than the SPI need plan, which may also result in a lack of stock. All of these factors and risks can be reduced by the safety stock.

The method is:

$$SSL = \frac{(1 + (1 - MPA) * F_p * (AFcst_{err} + k * \sigma_{err})}{D_e}, \qquad where \tag{34}$$

$SSL = Safety\ Stock\ Level\ [weeks]$
$MPA = Master\ Plan\ Adherence\ [percentage]$
$F_p = Frozen\ Period\ [weeks]$
$AFcst_{err} = Average\ Forecast\ Error\ [pieces]$
$\sigma_{err} = Standard\ Deviation\ of\ Forecast\ Error\ [pieces]$
$D_e = Average\ Demand\ [pieces]$

The calculation is based on a normal distribution, which requires a check to see if the data does show normal distribution, i.e. 68% of the forecast errors in each analyzed week should be within range of the average +/- one standard deviation.

It is important to know that this method is not supposed to be the answer to all safety stock choices. There are other factors that are important to consider when doing the final adjustments of the safety stocks. Business experts may add personal experience and expert factors on top of the calculation to consider factors which may not be part of the calculation. Additionally, there should also be a check to see if the stock is applicable in reality. For instance, the stock structure should be aligned with the frozen capital objective, the warehouse net storage capacity should be enough for all the stock, and any warehouse costs or rent should be considered. (Paetz 2017)

4.5 ERP-System M3

As a part of the global model Blueprint, IKEA Industry decided that all sites should use the same ERP system, Infor M3. Currently, 95% of the sites have implemented and are using M3. This facilitates easier information sharing and KPI follow-ups due to the fact that all sites are defining their operations in the same way. The joint usage of the same ERP system makes the implementation of joint processes, such as how to handle safety stock, easier.

The ERP system does also include ways of automatically calculating safety stock. To use one of the built-in features would decrease the time planners spend setting safety stock manually. However, there are also some downsides. Setting the safety stocks automatically in the ERP would make the planners disconnected from the decision, and getting an overview would be hard since the safety stock would be updated based on all new information gathered. This could result in several updates per article per week, and errors in the data could result in big output deviations.

Currently, M3 offers eight different ways of calculating safety stock:

1. Manually
2. According to the method:
$$SSL = Number\ of\ safety\ stock\ days * Daily\ consumption \tag{35}$$
3. According to the method:
$$SSL = Safety\ stock\ percentage * Lead\ time * Daily\ consumption \tag{36}$$
4. According to the method:
$$SSL = Safety\ factor * 1.25 * Mean\ Absolute\ Deviation\ (MAD) * \sqrt{Lead\ time\ [number\ of\ periods]} \tag{37}$$
5. According to set table of safety stock days
6. According to number of average issues
7. Mercia links
8. According to a Poisson table

Today, all sites use the first option, i.e. manually setting the safety stock. A few reasons could be lack of experience within the new ERP system, lack of data for some options, or simply keeping old traditions. Some sites have tried to do basic calculations, but these have always been outside of the ERP and then later inputted manually. Therefore, this option will be further evaluated for statistical methods. Another project that is ongoing simultaneously as this thesis is testing a safety stock model for direct material at the production site in Goleniow. However, this is also done outside of the ERP system.

The third option is not covered in the literature review, but it is similar to the first option. However, it calculates the number of days based on a percentage of the lead time demand. The fourth option in the ERP system is the same method as the third mentioned by Smith in the literature review.

Option 5 is rather similar to option 3, but harder to set up in M3. Option 6-8 are not applicable to IKEA Industry right now due to lack of data in the ERP system. Therefore, these options have been excluded in the following analysis.

4.6 Case Site - Lubawa

In order to produce all IKEA products, Lubawa holds over 2000 direct material articles in stock. Currently, there is no formal method for deciding safety stock, it is based on past experience for all products. About twice per year the safety stocks for direct materials are reviewed and updated if some major demand changes have occurred. However, this process does not follow any specified guidelines either.

As with most production sites, some articles are used more often than others are. Pictured in Figure 21 is the usage frequency plotted for each article and classified into 3 categories. 80% of all production lines represent only 20% of the articles, while the last 60% of articles only represent 10% of all production lines. A categorization based on usage frequency is preferable since safety stock management can then be based on how often an article is used. A value based categorization could be deceiving since the usage might be very concentrated and infrequent. No structured classification of products is done today, but Figure 21 indicates that a difference between the products exists and could potentially be used when deciding safety stock levels.

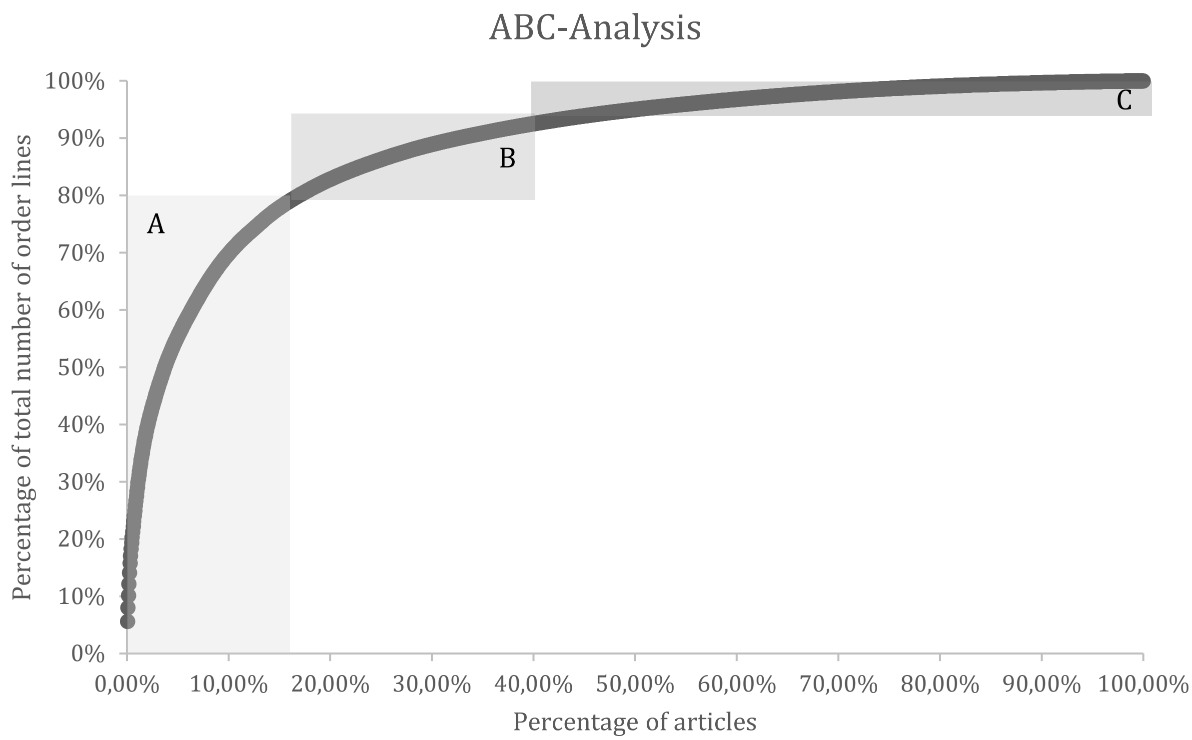

Figure 21. ABC overview of the Lubawa site.

5 Case Analysis and Findings

This chapter starts by answering the first two research questions and later moves on to how the models were evaluated. The chapter finishes with how the framework for IKEA Industry was developed, how it compares to today's work processes, and the pilot test in Lubawa.

5.1 Safety Stock Factors

The following research questions will be covered in section 5.1:

RQ 1: Which factors affect safety stock levels?

RQ 2: How do these identified factors affect the safety stock levels at IKEA Industry?

All the factors are listed and evaluated depending on their importance for safety stock levels in general. In addition to the general perspective, the perspective of IKEA Industry is highlighted. Lastly, it is mentioned if the safety stock formulas from the literature are covering the factor or not.

The factors that are considered less important are rejected and will not be covered further by the thesis. Section 5.1.8 summarizes all the factors that affect safety stock levels and highlights the most important ones.

5.1.1 Order Policy

The order policy is one of the factors that affect safety stock levels. Larger order multiples give a higher stock level on average, making the need for safety stock small during long periods of time. The effect is most noticeable for products with large order multiples that are produced in small, infrequent batches. As the order multiples decreases, the need for safety stock increases.

In the case of IKEA Industry, who uses MRP, there is no fixed reorder point. However, there are order multiples. The multiples are set in the ERP-system, and have been seen as fixed and outside of the scope of this thesis. From solely a safety stock perspective it would be interesting to investigate the order multiples, but these levels are already well considered and reducing the minimum orders could increase both the overall cost as well as the environmental cost.

5.1.2 Service Level

A service level is present in a majority of the methods for calculating safety stock. It allows the user to relate the safety stock level to a level of availability. Thus, the service level becomes a major factor in how large the safety stock should be.

IKEA Industry is currently working with service levels for finished goods towards IKEA, but not internally for the direct material stock for production. Towards IKEA, the service levels are divided into four product categories depending on the different agreements.

However, there is a KPI which is used in a similar way to service level, Master Plan Adherence (MPA). The MPA measures how well production follows the production plan, according to the produced quantity over a specified time period. When issues arise, whether due to machine problems or lack of stock, the production plan is changed to ensure a well-used production facility. The changes are also reflected by another KPI, Master Plan Changes (MPC), which measures the number of changes of the production plan, including both changes in quantity and date. Facilities reschedule production when potential issues arises, and as such they never experience any actual stockouts. The closest metric to service level is the MPA. Thus, the MPA can give a guideline to what service level can be a suitable target when calculating safety stock.

5.1.3 Demand Pattern

There are two aspects of the demand pattern that affects safety stock levels: demand variations and forecast accuracy. Variations in production depend on several reasons: variation in end-customer demand, the frequency of IKEAs orders, and how often IKEA Industry produces. IKEA Industry cannot affect customer demand since IKEA sets prices and plans promotions. What can be more easily changed is the production batch size. By producing more frequent, in smaller batches, the variation will decrease and thereby also the safety stock.

The frequency of IKEAs orders and the forecast accuracy are two demand aspects that increase the need for safety stock. The frequency is somewhat mitigated by the make to stock policy, but the accuracy cannot be completely mitigated by finished goods stock. Currently, the forecast is not great, with a correctness of about 60%. With better communication and improved forecast accuracy between IKEA and IKEA Industry, the correctness could be increased, which would lead to a reduced production uncertainty and reduced need for safety stock.

The importance of demand is reflected in the safety stock methods considered. All formulas from both literature and the ERP system have demand or demand deviation as a factor.

5.1.4 Lead Time

Second to demand, lead time is the most common factor in the formulas considered. The most important aspect is how well the suppliers deliver on time, i.e. the lead time variance. For suppliers that always delivers according to the agreed time, the lead time is not of such importance. However, for suppliers with both long lead time and large variance there is a need for safety stock.

The lead time is hard to improve without changing to suppliers that are located closer to the sites. What could be improved is the delivery uncertainty. For suppliers that are constantly late there could be benefits with either looking at the root cause of what is causing the delays or adjusting the expected lead time to reflect reality.

5.1.5 Component Commonality

Component commonality is not a factor that is commonly used in safety stock methods. One of the reasons may be that increasing commonality requires design changes of the product. This cannot be done by the logistics department alone, collaboration between several departments is needed, resulting in high complexity. To reduce safety stock, there are several factors discussed above that might have a bigger impact per invested resource, compared to redesigning current products. However, if product commonality is considered already in the design stage, the total amount of safety stock could be reduced.

5.1.6 Cost of Stock

Another area that affects safety stock level is the cost of stock. This is mainly viewed as cost of capital based on an internal rate of return. Few methods consider this directly, but the cost of capital is the main reason why safety stocks are not significantly larger. At IKEA Industry, the cost of capital has historically not been a large factor. This is mainly due to a relatively good cash flow, and the fact that stock has been considered more of an asset rather than a cost. However, new people in the management group have put effort to shed light on the cost of capital, making it more of a priority.

The bigger issue for IKEA Industry in regards to cost of stock has been the limited amount of storage space. As the production is increasing, storage space has become more of a scarce resource. At many sites, storage areas have been transformed into production space, and building new warehouses is expensive and difficult due to insufficient land. Therefore, cost of stock in terms of storage area has become a priority for IKEA Industry, and the goal is to find the appropriate amount of safety stock.

5.1.7 Product Quality

Product quality is the last factor that could affect safety stock levels. Depending on which quality both suppliers and shippers deliver, the demand for extra stock varies. IKEA Industry performs quality checks before, during, and after production. While some quality defects certainly occur, IKEA Industry has expressed that there is no direct issue and the levels are low. Therefore, product quality has been discarded in the following analysis.

5.1.8 Summary of Factors

Figure 22 provides an overview of which factors are considered important in the following analysis and Table 4 summarizes the impact these factors have on safety stock. Going forward, the three main factors that are important for deciding safety stock for IKEA Industry are the demand pattern, service level, and the lead times. These are the main factors that are included in the safety stock methods in the following analysis. The cost of stock is a factor with increasing importance due to the changing mindset of IKEA Industry. The factor is not directly covered by the safety stock methods, but the methods aim at finding the appropriate levels and thus indirectly assists in minimizing the cost of stock.

The remaining factors: component commonality, order policy, and product quality, are considered factors with none or low affect. Therefore, they will not be considered by the safety stock methods in the further analysis.

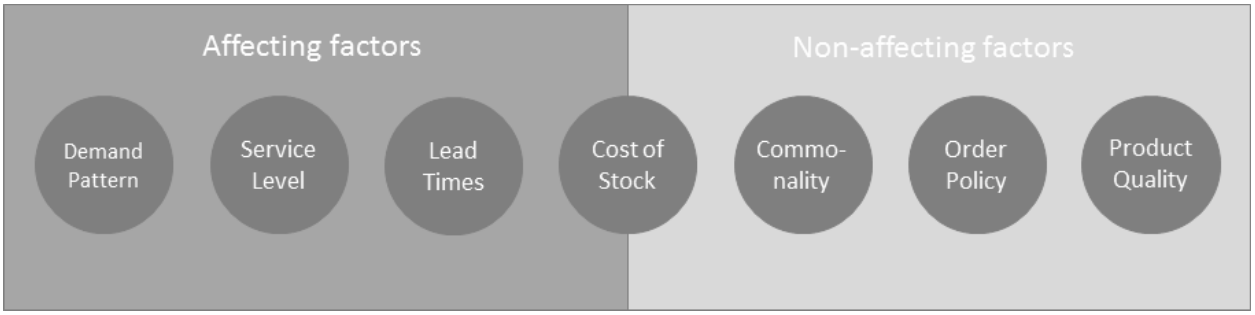

Figure 22. Overview of factors which affect the safety stock of IKEA Industry.

Table 4. Affecting factors and their impact

Factor	Safety Stock impact
Demand pattern	Increases safety stock.
Service Level	Increases safety stock and safety time.
Lead Times	Increases safety stock.
Cost of Stock	Limits the amount of safety stock and by extension, service level.

5.2 Evaluating the Methods

The methods considered as possible solutions consist of nine methods from the literature, presented in section 3.3.2, and three of the methods available in M3. These will be named as follows:

Lit 1: $$SSL = SF(SL) * \sigma_D \tag{21}$$

Lit 2: $$SSL = SF(SL) * \sigma_D * \sqrt{TRP} \tag{22}$$

Lit 3: $$SSL = SF(SL) * \sigma_F * \sqrt{TRP} \tag{23}$$

Lit 4: $$SSL = SF(SL)\sqrt{Var(U) + TRP * \sigma_D^2} \tag{24}$$

Lit 5: $$SSL = SF(SL) * \sqrt{TRP * \sigma_D^2 + D^2 * \sigma_{TRP}^2} \tag{25}$$

Lit 6: $$SSL = SF(SL) * \sqrt{Var(U) + TRP * \sigma_D^2 + D^2 * \sigma_{TRP}^2} \tag{26}$$

Lit 7: $$SSL = SF\left(1 - \frac{(1-SL)*QRP}{TPR*D}\right) * \sqrt{TRP * \sigma_N^2 + D^2 * \sigma_{TRP}^2} \quad \forall\, QRP < TRP * D \tag{27}$$

Lit 8: $$SSL = SF\left(1 - \frac{(1-\alpha)*QRP}{TPR(t)*D(t)}\right) * \sqrt{TRP(t) * \sigma(t)_N^2 + D(t)^2 * \sigma(t)_{TRP}^2} \quad \forall\, QRP < TRP * D \tag{28}$$

Lit 9: $$SSL = LSL_0 * (SL^2 - 1) + SSL_{100\%} * \sqrt[C]{1 - (1 - SL)^C}$$
$$\text{with, } LSL_0 = \frac{QRP}{2} \tag{29}$$
$$\text{and, } SSL_{100\%} = \sqrt{\left(DV_{d,max}^{+} * D\right)^2 + \left((D_{max} - D) * TRP\right)^2 + \left(DV_{QRP,max}^{-}\right)^2}$$

M3: 1: $$SSL = Number\ of\ safety\ stock\ days * Daily\ consumption \tag{35}$$

M3: 2: $$SSL = Safety\ stock\ percentage * Lead\ time * Daily\ consumption \tag{36}$$

M3: 3: $$SSL = Safety\ factor * 1.25 * Mean\ Absolute\ Deviation\ (MAD) * \sqrt{Lead\ time\ [number\ of\ periods]} \tag{37}$$

As mentioned in section 3.5, there are two basic dimensions of uncertainties: the nature of the uncertainty and the source of the uncertainty. Thus, this leads to four main areas of uncertainty: supplier timing, supplier quantity, demand timing, and demand quantity. These are the main aspects which a safety stock needs to consider and protect against. Table 5 below shows which of these aspects the different safety stock calculation methods consider.

Table 5. Illustration of which uncertainty aspects are considered in each method. Grey areas show the aspects that are considered in each method.

	Service Level	Supplier Timing	Supplier Quantity	Demand Timing	Demand Quantity
Lit 1	■				■
Lit 2	■				■
Lit 3	■			■	
Lit 4	■				■
Lit 5	■	■			■
Lit 6	■	■			■
Lit 7	■	■			■
Lit 8	■	■			■
Lit 9	■	■	■		■
M3: 1					
M3: 2					
M3: 3	■				■

One noticeable difference between the methods is whether they consider supplier timing, i.e. lead time deviations. None of the built in methods in the ERP system considers this and therefore the safety stock levels are not adjusted depending on how reliable the suppliers are. Moreover, all methods require that the demand is normally distributed, except for Lit: 9 that avoids this by focusing on the extreme values.

Based on the results presented in section 3.3.3, the methods lit: 2, 4 and 8 were excluded from further tests due to other methods performing better in all the situations tested by Schmidt et al (2012). Method lit: 6 takes the undershoot into consideration, which refers to a problem when the stock might already be below the reorder point before an order is triggered. This method was excluded since reorder points are not used in IKEA Industry. Finally, method 7 was excluded due to lack of data.

5.3 Simulation Setup

To test the methods, a simulation model was built in Excel. The model tests all methods on 23 articles that are representative of the whole according to supply planners in Lubawa, to see how well each method holds up to the target service level. Since not all methods are considering lead time deviations, which is an important factor for IKEA Industry, some adjustments have been made. The methods without lead time deviation are combined with a safety time that is calculated as proposed in section 3.4. The test is done by randomizing production forecasts, production frequency, forecast errors and delivery delays. The model calculates how many stockouts per year that would occur if one method was used and compares it to the current state. The input parameters can be seen in Figure 23.

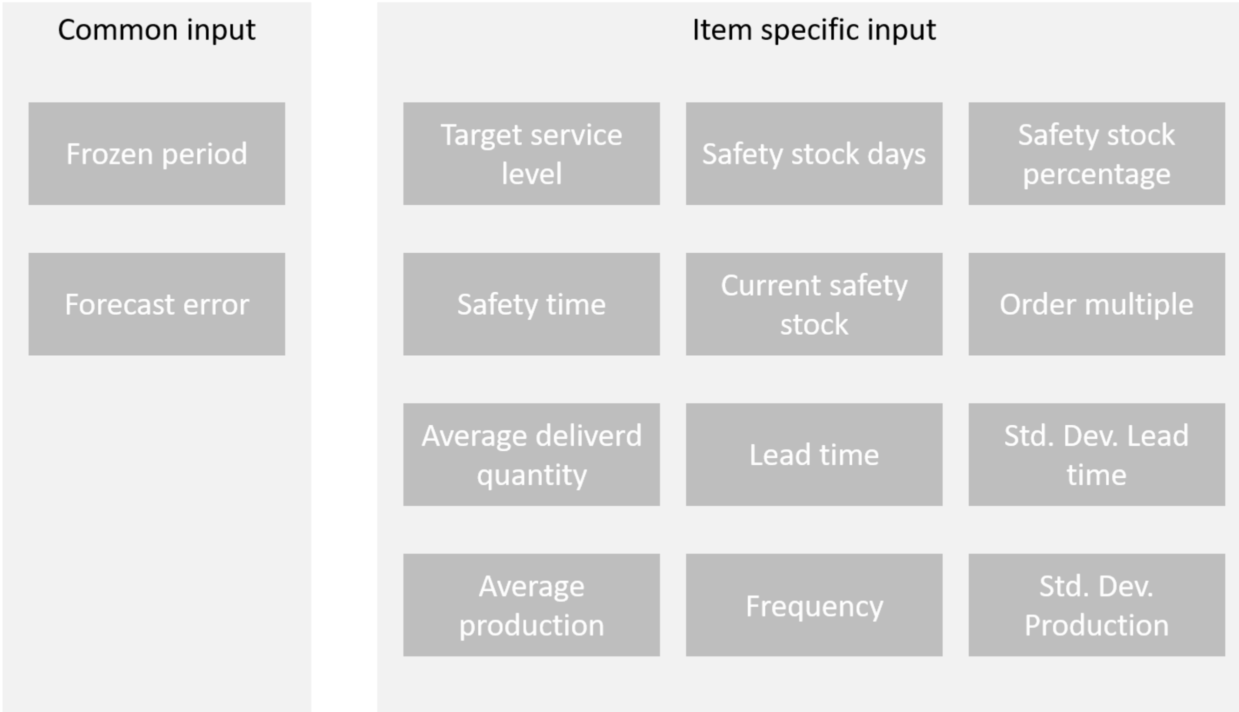

Figure 23. Simulation model input.

5.3.1 Randomizing Events

Production Frequency

Since an article is not used in production every day, the historical frequency, measured as order lines per day, was used to randomize how many order lines would occur each day. A discrete distribution with the same expected value as the historical average frequency was used when randomizing the number of order lines.

Forecasted Production

The production forecast was based on a normal distribution with mean and standard deviation calculated from historical data. For each day, a production forecast for one order line is generated and then multiplied with the randomized number of order lines for that day. Resulting in a total production forecast generated for each day. See Figure 24 for a histogram over historical production data for two articles. An early delivery may indicate unreliable deliveries from a supplier and create issues in the receiving and stock areas.

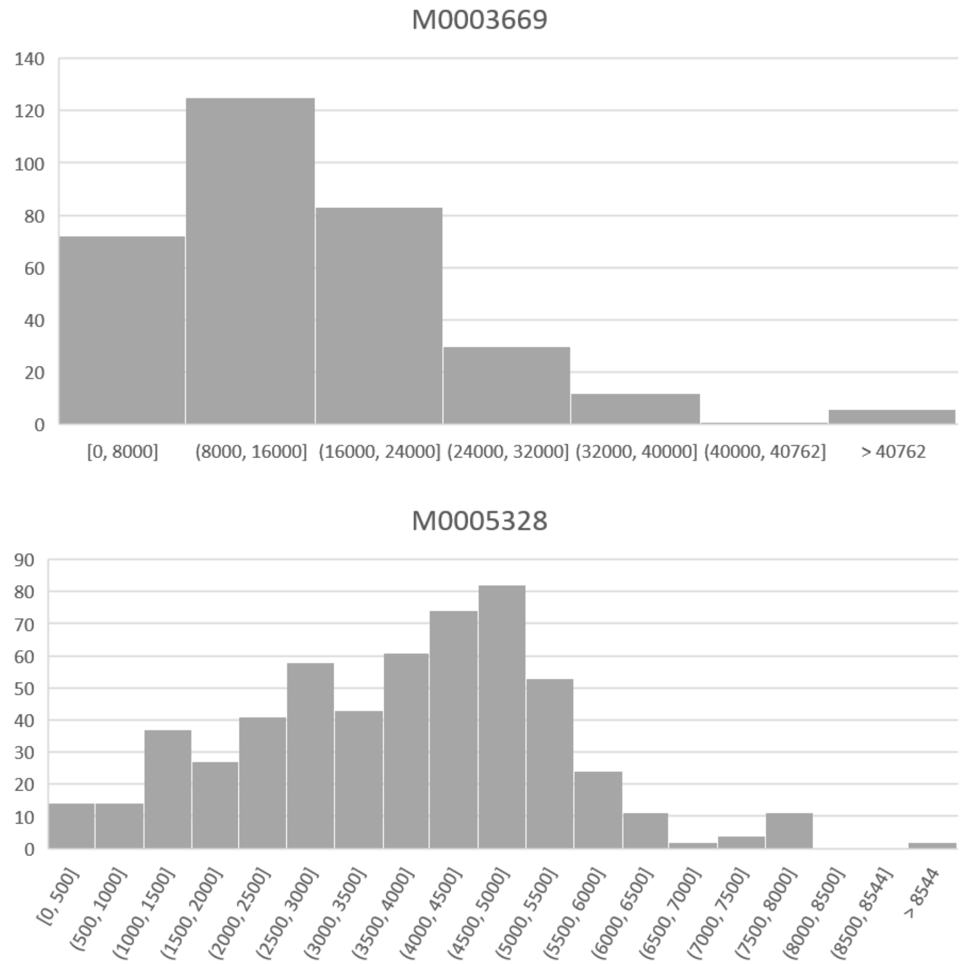

Figure 24. Histogram over production for two articles.

Forecast Error

Since the real production differs from the forecast, a forecast error is also simulated in the model. The error is based on a normal distribution with mean 1.0 and standard deviation based on the Supply Plan Quality, a KPI which measures how well IKEA's demand follows their SPI from eight weeks before the production. Thus, the error is a factor that is multiplied by the forecasted production to get the actual production for each day.

Delivery Delays

Delivery days are considered to follow a normal distribution. Even though a negative delay, i.e. an early delivery, might not be considered a delay, the model does consider the possibility that a transport arrives earlier than requested, which is a possibility supported by the historical data. See Figure 25 for a histogram over delivery delays for two articles.

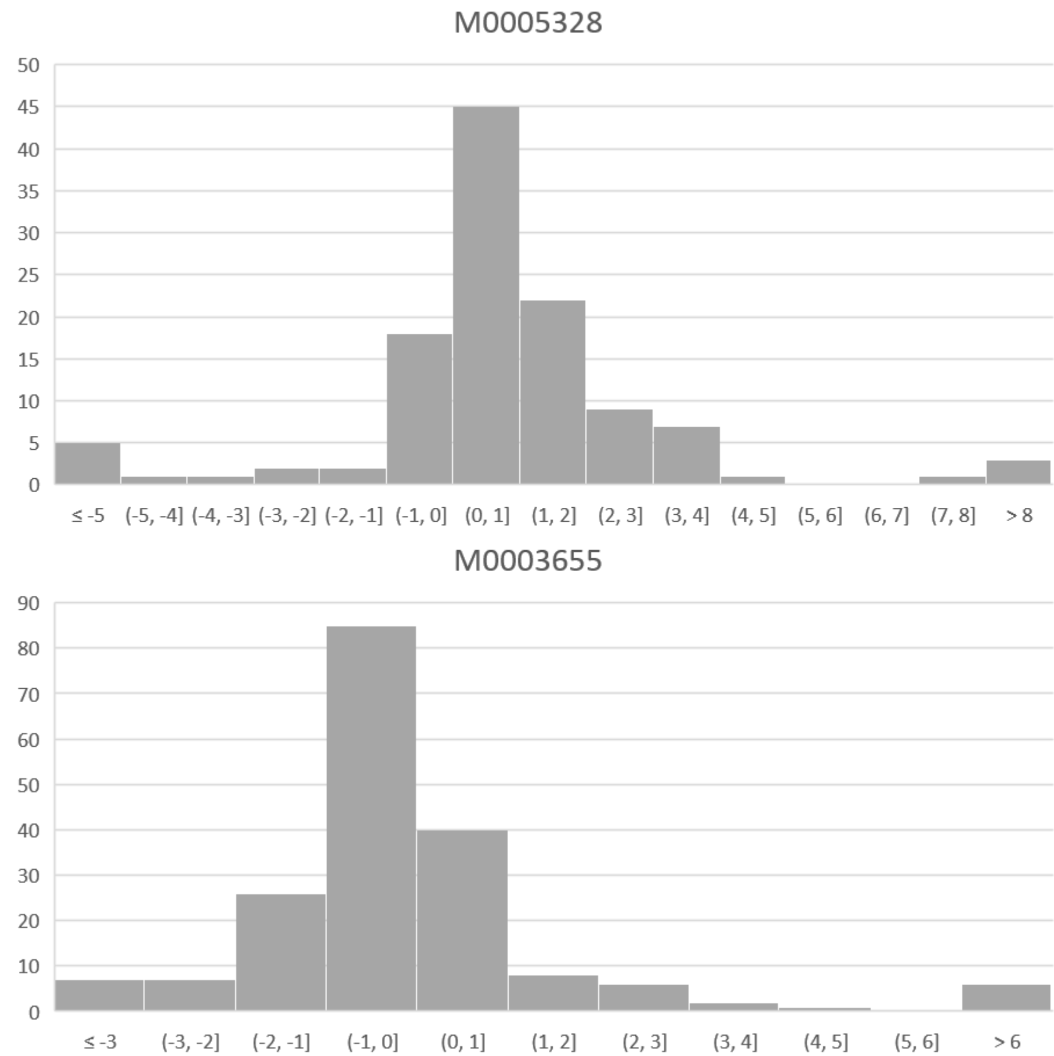

Figure 25. Histogram over delivery delays for two articles.

5.3.2 Calculations

Current Stock

The current stock is based on the stock from the previous day, adding any incoming orders and subtracting the production of the day.

Placing Orders

Direct material orders are placed a number of days, corresponding to the safety time plus the lead time, before the production day when the ordered stock is needed. The purchaser is expected to consider the current stock, all planned deliveries and production up until the future production day, and any deliveries that are currently delayed or have arrived early. When the future expected stock is negative, an order is placed to arrive at that date. The order is dimensioned as the number of order multiples needed to bring the expected stock above zero, but at least enough to cover the planned production. The order arrival is based on the expected lead time with the safety time subtracted and the delivery delay added.

Service Levels

The service level in the simulation is defined as the proportion of production days when the stock could cover the production demand, thus not inducing a change in the production schedule.

5.3.3 Assumptions

In order to create a simulation model, some assumptions and simplifications are necessary.

Orders are assumed to be planned to arrive on the production date. This simulates a supply chain where stock should not be kept in storage for longer than necessary. The assumption diverges from reality based on that it means all orders will be produced over a period of one day. However, this should not be an issue since it is only an offset of time and the order would simply be ordered a few days earlier to arrive at the start of the production period, if the production process takes more than one day.

Currently in the Lubawa facility, orders are scheduled to arrive on Friday the week before production. This is a way to handle a certain uncertainty in which order the weekly production will be scheduled. The daily production schedule is set after the material orders have been placed and thus require all materials to be available on Monday. Based on this, the simulation has an added three-day safety time for the current setup, which represents the average time before production each delivery is scheduled to arrive.

When calculating the standard deviation of delivery delays, a delivery delay is defined as the difference between the requested delivery date and the receipt date. The current way of measuring delays at IKEA Industry is to compare the confirmed delivery date with the receipt date, giving the supplier a more forgiving measure. However, using the requested delivery date represents a higher trust in the agreed lead time. If there is a large difference between the measurements, it might be necessary to investigate the supplier relationship and perhaps adjust the agreed lead time. With the simulation setup, the planner won’t have to add some extra time just in case the supplier confirms a date later than the requested delivery date.

5.3.4 Analyzed Articles

The simulation focuses on 23 articles from a variety of product groups, which can be seen in Table 6. The articles were chosen by planners at the Lubawa site to make out a representation of all articles.

Table 6. Items with corresponding product groups used in the simulation.

Item	Product group
M0003257	Honeycomb Paper
M0003655	Edges Plastic & Paper
M0003669	Edges Plastic & Paper
M0004520	Honeycomb Paper
M0004542	Honeycomb Paper
M0004750	Lacquer & Paint
M0004757	Lacquer & Paint
M0005328	Honeycomb Paper
M0323376	Edges Plastic & Paper
M0323555	Board
M322112	Fittings & Metal Components
M326953	Fittings & Metal Components
M9001463	Board
M9004027	Adhesives
M9004085	Lacquer & Paint
M9013740	Lacquer & Paint
M9013938	Board
M9014633	Board
M9014635	Board
M9015659Y	Board
M9017863	Plywood
M9017865	Plywood
M9018443	Adhesives

Table 7 shows the item characteristics regarding lead time delays. As seen in the table, the items differ a lot from each other. Some suppliers are regularly able to deliver on the requested delivery date, while others often need to confirm a later delivery date, thus causing a delay according to the definition used in the simulation, as mentioned in section 5.3.3.

Table 7. Item lead time delay statistics.

Item	Average Lead Time Delay	SD Lead Time Delay
M0003257	1,72	3,13
M0003655	0,38	2,63
M0003669	1,21	3,53
M0004520	0,52	1,59
M0004542	0,00	2,23
M0004750	-0,12	1,79
M0004757	0,07	2,16
M0005328	0,85	4,92
M0323376	2,33	3,73
M0323555	1,97	5,57
M322112	-1,10	3,75
M326953	1,65	3,54
M9001463	-2,25	4,43
M9004027	0,00	0,00
M9004085	0,62	0,97
M9013740	0,84	1,57
M9013938	2,61	8,74
M9014633	10,41	13,81
M9014635	13,23	9,81
M9015659Y	1,80	1,79
M9017863	9,56	10,90
M9017865	9,65	13,87
M9018443	1,07	3,69

5.3.5 Simulating

The simulation is based on an Excel macro which begins by calculating the production frequency distribution, using the Excel solver to reach the desired average frequency. This is followed by randomizing values of forecasted production, forecast errors and order delays for each day. The next step is calculating the stock levels, orders, and finally the service levels. Afterwards the service levels are copied into a separate table. In order to see how well each method performs over time, the simulation is run 100 times for each of the 23 articles. This allows the result to capture reasonable values for lowest, average, and highest results. The simulation is performed for target service levels of 70, 80, 85, 90, 95, and 99 percent.

5.3.6 Simulation Results

The purpose of the simulation was to determine which safety stock method would have the best performance. The comparison was based on how close each method came to the target service level. A method that does not reach the target is obviously not very good. But neither are methods which reach service levels which are higher than the target, since the suggested safety stock would be higher than necessary. Thus, the chosen performance measurement is how much each method on average deviates from the target service level. The goal is to have as small deviation as possible.

Results from the simulation can be seen in Table 8 as the average, maximum and minimum deviation from the target service level. As seen in the results, the best performing formula according to the simulation is the third formula from the literature. Where safety stock is calculated as:

$$SSL = SF(SL) * \sigma_F * \sqrt{TRP} \tag{23}$$

Safety time is calculated as:

$$ST = k * \sigma_{LT} \tag{33}$$

Table 8. Deviations from target service level for different safety stock methods.

Deviation	Current	Lit 1	Lit 3	Lit 5	Lit 9
Average	11,06%	3,35%	2,81%	15,45%	7,84%
MAX	20,84%	6,21%	4,99%	17,29%	19,40%
MIN	1,84%	2,31%	0,75%	12,96%	0,99%

A comparison of the results achieved by this safety stock method and the currently set safety stock can be found in Figure 26. The suggested method follows the movements of the current safety stock to a large extent, but remains closer to the target service level. Further illustrations of the other methods can be seen in Appendix B.

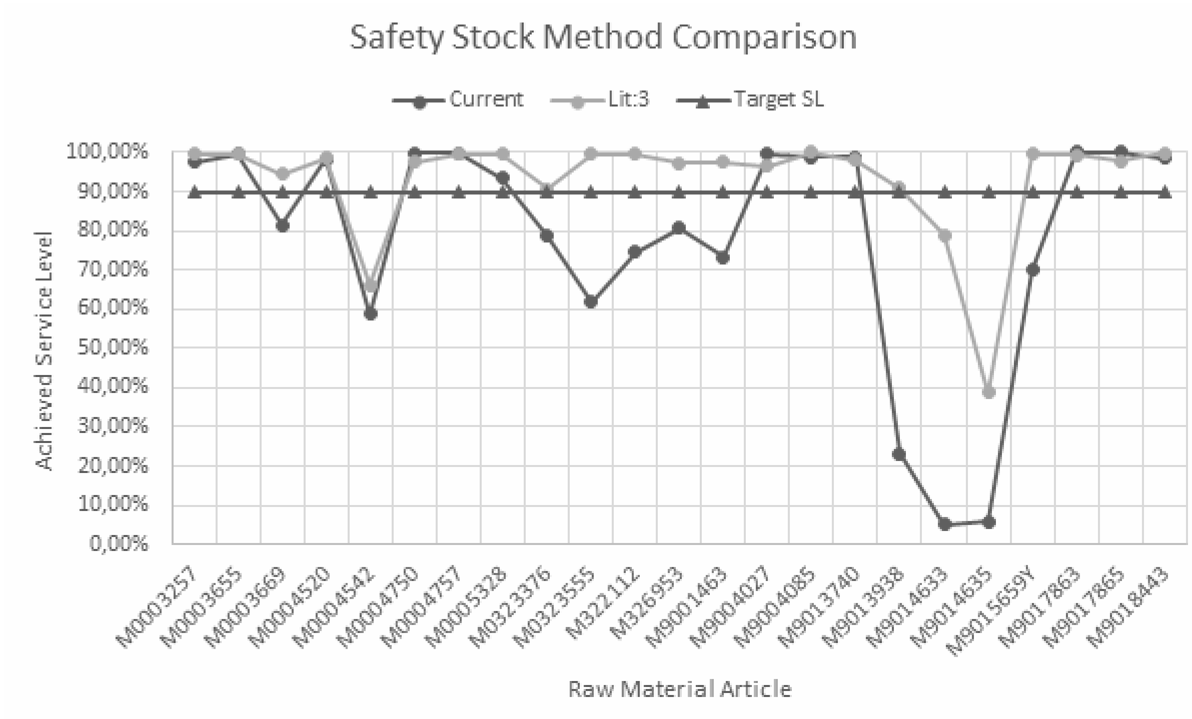

Figure 26. Comparison of achieved service levels for different articles and methods.

As mentioned in section 4.3, the currently set safety stock varies depending on the material group and the perceived necessity of the article. This can also be seen in Figure 26, where some articles reach a high service level, while others are quite low. The achieved service level varies a lot between the different articles.

One reason to why some articles reach such low service levels is that they have large delays and delay deviations. While the delay deviation is covered by the safety time, the average delay is neither taken into consideration in the safety stock methods nor the safety time calculation. Delivery delays are such a fundamental issue that regular delays should not be covered by safety stock. Instead, the delays should be brought up in negotiations with the supplier since they clearly cannot maintain the agreed lead time.

However, the large deviations might also be traced to the measuring of delivery delays. In the model, a delay is defined as the difference between the requested delivery date and the receipt date. Meaning that when the supplier confirms a date that is later than the requested date, it will be considered a delay. However, it also means that when the planner at IKEA Industry changes the confirmed delivery date, it will also be considered a delay even though it was a deliberate delay.

Overall, the suggested safety stock method proposes a redistribution of the safety stock between the articles compared to the current setup. This would lead to lower safety stock for a few articles that currently have very high service levels, and a higher safety stock for the articles which are not being prioritized in the warehouse storage.

5.4 Developing a Framework

The framework is based on two factors: the method that was closest to the target service level and a product classification. The best performing method will be a basis for calculating the safety stock with a safety time addition, since the method is not covering lead time deviations. Furthermore, the article classification based on the number of production orders, as shown in section 4.6, will be used to distinguish low frequency articles to the ones that are produced often.

The differentiation between articles will help to avoid high safety stock turnover time. For articles that are demanded few times per year there is no need to have a fixed amount of safety stock on hand at all times. A more efficient way would be to apply a safety time for those low frequency articles, hence removing safety stock completely. By doing this, safety stock that covers demand variations will be lost, but lead time deviations on every article will still be covered. For production sites that have reached a relatively high plan accuracy, the demand uncertainties will be reduced and this solution will cover a higher share of the total uncertainties. The framework is based on the results of the simulation. The formula closest to target service level is the one that the framework is based on. An overview of the framework can be seen in Figure 27.

	Safety time	Safety stock
C-articles	$K * \sigma_{Lead\ time}$	0
A and B articles	$K * \sigma_{Lead\ time}$	$K * \sigma_{prod} * \sqrt{Lead\ time}$

Figure 27. Framework overview.

Since it is not possible to do the necessary calculations in the ERP system, a tool for managing the calculations is needed. A prototype was developed in Excel, but it could be further developed into a QlikView application or similar after this thesis.

5.4.1 Concept Development

For IKEA Industry there have been two major wishes for this thesis; the developed tool should be understandable, and easy to use. As for the understandable part, the building blocks of the formulas should be somewhat comprehensible for people without a degree in logistics. Some of the formulas presented in the literature would probably be too complex, and therefore the rollout and usage of the tool would most likely decrease if one of those would have been chosen.

The tool should consist of three parts; data input, calculations, and lastly displaying the results. A planner should be able to receive the necessary data from the ERP system, import it into the tool, and then the calculations should be performed automatically. The planner can later put in the results back to the ERP to update the safety stock, see Figure 28 for a high-level overview.

Inbound data		
General information	**Production**	**Delivery**
Item Number	Warehouse	Purchase order number
Warehouse	Manufacturing order number	Item number
Allocatable on-hand balance	Component number	Received quantity
Lead time	Reporting date	Receipt date
Safety stock	Reported quantity 1	Confirmed quantity
Order quantity		Requested delivery date
		Number of partial deliveries

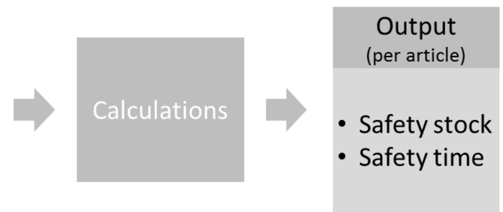

Figure 28. Decision support tool structure.

To mitigate the risk of people in the organization thinking the tool is too complicated, or that they do not see the purpose of using a safety stock calculation tool, an introduction poster was created. The poster will go out to the planning department for each site and act as an introduction to the new working processes. The purpose is to familiarize co-workers to the concept of safety stock and the importance of using it, as well as teach them of how to use the new tool. The poster can be found in appendix D.

5.4.2 Application Development

Excel

The first version of the tool was developed in Excel. The reason behind this was to quickly get a functioning tool with all the logic working. All planners have access and use Excel on a daily basis, enabling them to understand and use the tool. Moreover, extracting data from the ERP system is easily done to Excel, reducing the time to set up the model. The tool could be presented to the organization and the end users to get an understanding of how the tool works, and get input on future development. Working with an Excel model gives the possibility to quickly revise and update the model so it fits the needs of IKEA Industry.

There are some best practices when building an Excel model that should be applied to increase usability. Balik (2009) suggest that the structure of an excel workbook should follow a chronological order. That is, instead of placing everything in one sheet and potentially confuse the user, the model should consist of several sheets that the user will go through one by one. This does not only increase usability, but also decreases the risk of user and model errors since you are not overwhelmed by information.

The tool consists of three main sheets; input, calculation, and output, in addition to an introduction sheet as suggested by Garrett (2015). The introduction sheet is an explanation of how to use the tool, what data is needed, what the tool calculates, and finally how the user should interpret the result. At the input sheet, the user is asked to input the necessary data, which has previously been extracted from the ERP system.

To aid the user, input cells are colored, to signal to the user how to interact with the sheet (Garrett 2015). The calculation sheet automatically performs the necessary calculations, and the user should not need to use this sheet at all. Lastly, the suggested safety stock and safety time levels, together with the financial impact is presented in the results sheet. By doing this, the user can see both how a certain service level effects individual items stock levels, as well as on an aggregate level.

Excel models also have some drawbacks; users can unintentionally change something, the model might stop working if there are updates in the ERP system, or the Excel models can be forgotten or not used due to the fact that it is hard to update with new functions. Therefore, the Excel model is great as a proof of concept and to spread the word within the organization, but in the case of IKEA Industry it is not a long term solution.

QlikView

For other similar applications and as a business intelligence software, IKEA Industry uses QlikView. To build a QlikView application was not included in the scope of this project, but initial development has begun. The advantages of a QlikView application over an Excel model are many. The most prominent one is that the user does not have to extract any data manually from the ERP system, hence saving time and reducing the risk of error. Furthermore, a QlikView requires almost no introduction and can be easily shared within all sites, enabling benchmarking and follow-ups with the press of a button.

The development of a QlikView application was initiated at the end of this project. Initial development and design meetings have been held, where the structure and functions of the final application were suggested. The proposed structure is very similar to the Excel model, since the underlying logic is identical. However, the proposed QlikView application has some additional features. Firstly, getting a breakdown of different aspects is much easier in the QlikView applications. Showing results based on product groups or changing the period the data is based on, is more intuitive and easier done. This enables the planner to look at different levels of aggregation and also how different time periods affect the suggested safety stock and safety time levels. Secondly, being able to use the forecasted production data will enable the calculations to include future production changes. Finally, since the data is always up to date in a QlikView application, it is possible to earlier change values for discontinued articles, and spot deviations in new articles. Work instructions for the QlikView application can be found in Appendix C.

A clear advantage with a QlikView over an Excel application is that it is much easier to benchmark between different sites. This enables a much easier way to compare the sites that are performing well to those that need help with setting up their safety stocks. A QlikView could also show a breakdown of the ingoing aspects in the formula, enabling planners to work proactively to reduce deviations where it is most needed. By implementing this tool, more than safety stock and safety time could benefit.

5.4.3 Further Development

This thesis has initiated the development of a direct material safety stock decision tool for IKEA Industry. To further enhance the tool from a usability perspective, the first step for IKEA Industry would be a rollout of the initiated QlikView model to all sites. In addition to this, steps towards a more automated process should be taken.

There is an extension to IKEA Industry's ERP system that can automate data extraction, calculation, and mass input. Incorporating safety stock and safety time calculations into this tool would enable the ERP system to continuously update the levels based on the latest information, while freeing up time for the planning departments. This would allow the planners to spend more time on analyzing changes and do follow up with suppliers that are often late with their deliveries to reduce the needed safety stock.

5.5 Comparing to Today

By using the developed tool for calculating safety stock and safety time, the impact cannot be seen on the aggregated numbers, as shown in Figure 29 and Figure 30, but it can be seen on a unit level. The aggregated values show the total change in safety stock value and number of units, as well as how much extra on-hand capital would be needed to reach a specific service level. Comparing the current number of units in stock with different service levels shows that the number of units in stock today is fairly similar to 80% service level. This is also the result of the performed simulation. Unsurprisingly, the number of units increases drastically the closer you get to a 100% service level. However, looking at a unit level will give some more exciting changes from today's values.

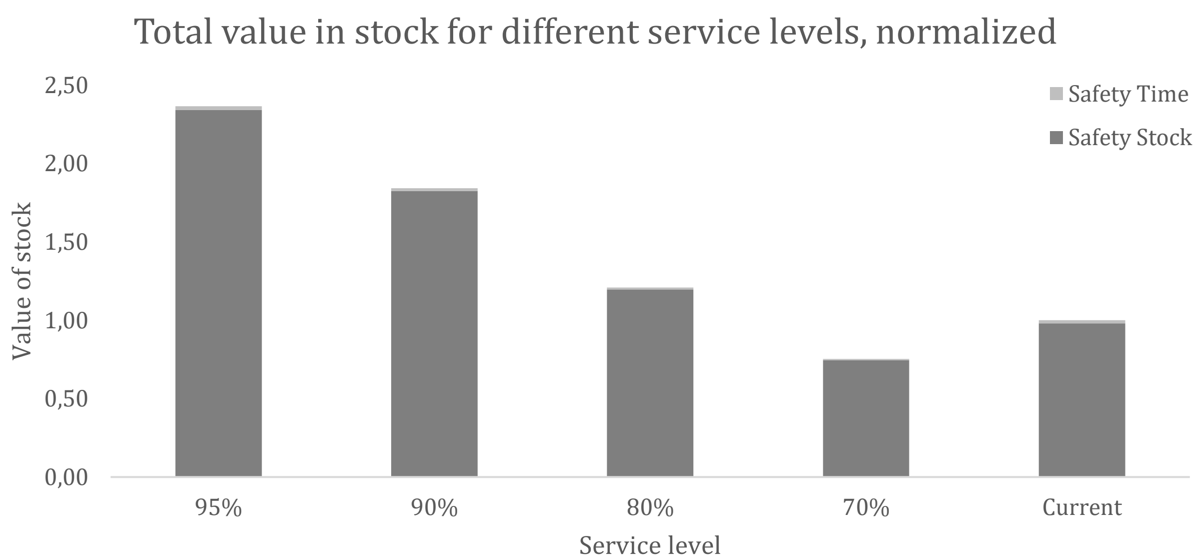

Figure 29. Normalized changes in total value, Lubawa.

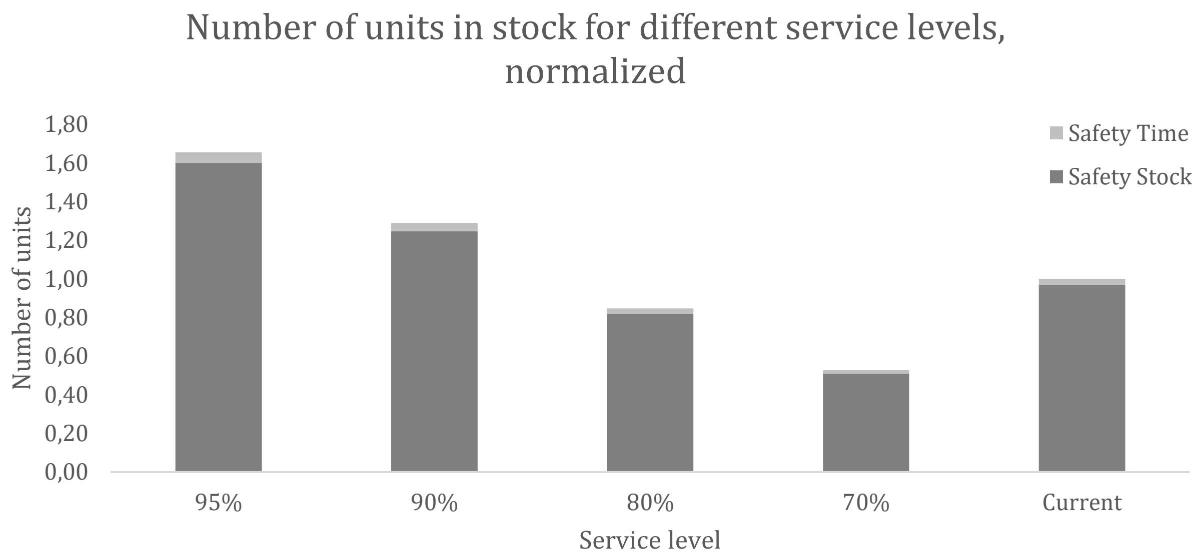

Figure 30. Normalized changes in total units, Lubawa.

Looking more closely at the product group edgebands at Lubawa, and more specifically at the ten articles with the most and least safety stock right now, there is a clear difference in the suggested stock levels for 80 % target service level, see Table 9. Currently, Lubawa keeps about one week of supply in safety stock for the top ten articles, which is also the frequency with which they receive deliveries. For these articles, the safety stock method suggests a lower safety stock, but also some safety time.

On the other hand, the ten articles with the lowest safety stock have no safety stock at all. For these articles the method suggest on average a lower stock than for the top 10 articles, but still significantly higher than zero. This shows that there is some connection between how the planners have thought and how the tool works, but that the planners are going more to the extreme. They have either a lot in stock, or nothing at all. For this reason, it is also dangerous to compare the mean. On average it seems like the tool and the current safety stock suggest rather similar results in terms of units and value for a service level around 80%, but in reality the current stock has a much higher spread in how it is divided among the articles.

Table 9. Suggested safety stock and safety time for edgebands.

	Safety Stock		
Item number	**Current**	**Suggested**	**Suggested safety time**
M0003615	100000	16682	2,6
M0003612	100000	16760	4,4
M0323454	100000	62710	3,6
M0323457	100000	19312	2,9
M9003956	100000	20645	2,7
M0003696	90000	78304	6,9
M0323462	86550	28550	1,5
M0323495	85000	47510	2,2
M9004749	85000	54302	2,3
M0003655	83000	46021	2,5
M0324265	0	16576	0,9
M0324266	0	18135	2,0
M0324268	0	32060	28,5
M0324269	0	25004	15,4
M9003929	0	380	0,9
M9005733	0	29976	16,3
M9005734	0	21801	6,8
M9012256	0	22732	0,0
M9018831	0	3881	4,4
M9021130	0	3901	29,0

5.6 Testing in Lubawa

The pilot in Lubawa consists of implementing the recommended safety stock levels and safety time for five different articles in the edgeband group. Articles were chosen by the supply planners as appropriate test articles. The aim was that this test should give a first indication of how the results would differ compared to the current safety stock, and an impression in how well safety time works as a buffer. Edgebands were chosen as test group due to being a frequently used articles which may show a difference in the short time limit of five weeks. From this group, the five specific articles were chosen based on not being the essential articles, while still having a high frequency. Additionally, articles were chosen so that they included both suggested increases and decreases compared to the current safety stock, in order to be able to measure both perspectives. For the articles that will have an increased safety stock and safety time, the purpose is to see if the extra stock increases article availability, while for the articles with decreased stock, the question is if and how much it decreases article availability.

Due to the limited time frame of a master thesis the first tests was conducted over a five week period. This will be enough to give preliminary results, but more extensive testing will have to be made depending on the outcome. Since it takes some time for the stock to adjust to the new level, and orders are not produced more than a couple of times per week the test would ideally be extended to cover at least a quarter.

The measurement of the test is how many stockouts occur during the period, compared to the previous setup. With the target service level of 95% the number of stockouts is expected to be low, which is critical as these articles are frequently used in production and quite high safety stocks have been held in the current setup.

5.7 Summary of Results

Based on simulations of different safety stock methods for 23 different articles, the recommended safety stock method is a combination of safety stock and safety time that reached a service level close to the target service levels. The method is calculated as:

$$SSL = SF(SL) * \sigma_F * \sqrt{TRP} \tag{23}$$

$$ST = k * \sigma_{LT} \tag{33}$$

The resulting safety stock differs a lot from the currently used safety stock. Deviations include both suggested increases and decreases, resulting in a redistribution of the safety stock. The current safety stock approximately corresponds to a service level which is slightly below 80%.

6 Conclusion

The thesis ends with some final conclusions, recommendations to the case company, and a discussion. Lastly, some potential future research topics are presented.

6.1 Revisiting the Research Questions

This master thesis has aimed to find a method for IKEA Industry to use when working with safety stocks for direct materials. The current way of working, where each planner work in different ways without any consistency between the different facilities, has several areas of potential improvements. A standardized tool that is used by each planner allows new planners to more easily understand how the safety stocks have been set. It can also become a tool for the management to use when analyzing safety stocks. Finally, it might also make the decision process more efficient as the planners will not have to manually calculate the safety stock and can put their time into analysis and other value adding activities.

The process for finding the safety stock method has followed a path of the three research questions, which will be discussed below.

RQ 1: Which factors affect safety stock levels?

The first research question is solely based on the available theory. Therefore, it was answered through a literature review which went deeper into each area to create a knowledge base for the second and third research questions. The identified factors can be seen in Figure 31.

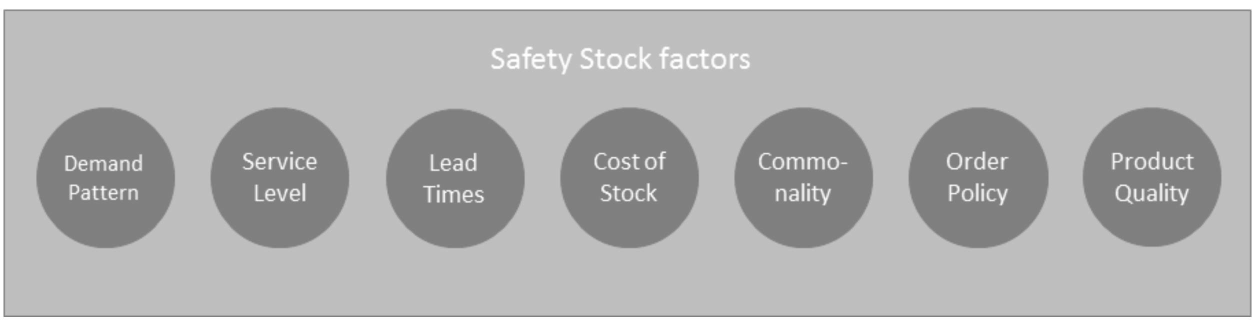

Figure 31. Identified safety stock factors.

RQ 2: How do these identified factors affect the safety stock levels at IKEA Industry?

The identified safety stock factors from the first research question were then analyzed to see which would be relevant for IKEA Industry. Relevant ones were kept for further analysis, while the non-relevant ones were discarded, see Figure 32.

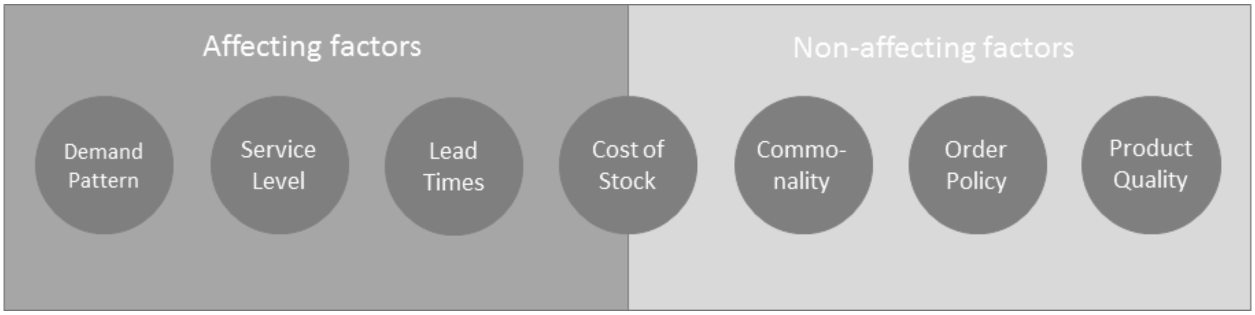

Figure 32. Overview of which factors affect the safety stock of IKEA Industry.

The list of relevant factor was further developed to cover the second research questions and find in what way each factor would be important for the final research question. How each factor affects the safety stock for IKEA Industry can be found in Table 10.

Table 10. Affecting factors and their impact.

Factor	Safety Stock impact
Demand pattern	Increases safety stock.
Service Level	Increases safety stock and safety time.
Lead Times	Increases safety stock.
Cost of Stock	Limits the amount of safety stock and by extension, service level.

RQ 3: How should a standardized tool be developed to be able to continuously estimate safety stock levels at IKEA Industry's factories?

The final question was answered by the development of a safety stock framework. First, the different safety stock methods were tested in a simulation to find the appropriate one for the framework. The appropriate method was considered to be the one that performed closest to the target service level.

The framework was developed with two key points in mind, simplicity and adaptability. Simplicity by making clear instructions for the few actions the user needs to perform in the excel model. This includes downloading data from the ERP system, pasting the data into clearly labeled columns, entering the desired data for service level and classification, and finally updating the tables. Adaptability by providing options for the user to decide the desired service level, classification categories, and a visibility of the calculations for further analysis. With the upcoming QlikView application, the manual actions required will be reduced by having the data importation and table updates automatically run by the application. The user can then focus on the analysis and decision making process, improving the simplicity of the framework.

6.2 Recommendation

Our short term recommendation is that IKEA Industry starts introducing the framework in the facilities as a support tool when working with safety stock and safety time. The advantage of the tool is that it can create awareness of important factors to consider when deciding safety stock levels, and act as a point of discussion for further improvements in the daily operations. For example by showing which products have high volatility in demand or lead times. However, it is important to notice that the tool has gone through limited testing and should be tested further before being fully implemented as a decision tool.

When going forward with the long term plan for the project, there are a few improvements which can be made to simplify the process. Firstly, the continued development of a QlikView model will allow the users to avoid manually importing the necessary data. It will also make it easier for central management to view safety stock calculations for different facilities. Secondly, the data import into M3 should be improved. Currently, it will require manual input for each article, regardless of the decision tool. Even though a mass update tool is currently used, it will still require setting the safety stock level for each article. Thus, an adjustment to the update tool to allow pasting several values at once, or incorporating a new tool for updating would be a great improvement for facilities with a large number of articles. Currently a new data handling tool is being implemented which might be able to handle a safety stock framework and could provide a very efficient solution. Finally, it could be advantageous to use ERP functionality, and therefore, it would be interesting to collaborate with the ERP developer to see if this feature could be implemented in the near future.

In the future, it would also be advantageous to change the safety stock calculation from production deviations to forecast error deviations, as suggested by the literature. Forecast error is not currently measured in the factories and it would require new data handling of the forecasts, which are currently not saved in the ERP system. Such an improvement would give a more appropriate safety stock level, since it would reflect how well each facility can forecast the production even if it may be large deviations in the production quantities.

Overall, the framework is supposed to act as a support tool. Not all facilities are identical and there are shortcomings in the methods used. Thus, some facilities might need to adjust the suggested safety stock levels to reach appropriate numbers. However, the added benefits of a good starting point and a standard framework used in all facilities makes up for these shortcomings.

6.3 Discussion

The developed tool should be seen as a support tool and the output numbers should not be treated as facts. There could be reasons why an article should have a different safety stock or safety time than suggested by the tool. For example, the planner might know from past experience that a higher safety stock should be kept due to circumstances that are not considered in the formula, such as high scrap rate. Limited space could be another reason for the safety stock to be lower than suggested. Moreover, new articles or articles with new suppliers will not have sufficient data to give an exact suggestion. A method will never work perfectly for all cases, and it should be kept in mind when using it.

The tool is aimed for use within IKEA, but as long as the data input matches the requirements, it would be possible for other companies as well. However, it should be noted that the simulations have been with IKEA Industry data, for other companies or for finished goods another formula could potentially be better suited.

The output of the safety stock and safety time tool was validated by testing the suggested values on five articles at the case site. The preliminary results from the tests suggest that the result is reasonable. However, this test is too small for any significant results, both in regards to time and number of articles tested. For a more thorough validation a longer test with more articles should be conducted. Preferably, another site should do the same tests to ensure that the results can be applied to all production sites. It is also important to notice the constraint of warehouse space which might limit the possibility to fully follow the recommendations from the decision support tool.

A potential improvement to the tool is to base the standard deviation in the safety stock method on deviations from the forecast, rather than production quantity deviations. However, this is not currently possible due to limitations in the ERP system and IKEA Industry's internal processes. However, if a change was made to enable the forecasts to be saved, the authors would recommend considering changing the standard deviation.

Reflecting back to the studies by Schmidt et al. (2012), the conclusion can be made that the research is consistent with the result of this thesis. The case site could be considered as a site with high variations in both production and lead time. However, since the safety stock is used for direct material instead of finished goods, the high demand variation is less relevant. In the simulation, method three did perform in the top, which fits with the conclusions made by Schmidt et al. This could imply that the formula generally performs well for companies with the same variations. However, before making too large generalizations, further tests should be performed at other sites, possibly in future master theses. Another aspect that can affect the result and should be further researched is the use of MRP. At the case company MRP is used and it is possible that a company with similar settings, but without MRP implementation would get different results.

In the final steps of the project a new coworker introduced himself to the authors since he recently had been working on a similar project for another company. Their solution and his suggestion were based on simplicity, rather than statistical calculations. However, according to the co-worker, the results of their implementation was promising. Due to the late introduction and the fixed time schedule for the master thesis, the previous project could not be evaluated and potentially integrated into the thesis. Therefore, IKEA Industry should look into the project more thoroughly, since there might be parts that can improve the implementation and the usability.

The theoretical contribution of this master thesis is twofold; applying theory from finished goods stock to direct material, and determining a safety stock standard suitable for an international company. The thesis has tested several methods that are mainly used for finished goods and applied them to a direct material buffer scenario. This could be used by producing companies to get a better understanding of the factors affecting direct material safety stock, how to use a statistical approach to an automated method, and how to incorporate safety time. Moreover, since most literature covers finished goods rather than direct material, this thesis could be seen as a proof of concept for the applicability of finished goods methods on direct material safety stock.

For the academia, the investigation of safety stock and safety time has previously not gotten much attention. Some researchers, e.g. van Kampen et al. (2010), have compared the two methods, but the possibility to combine them is seldom investigated. Furthermore, this thesis also provides an investigation of a company case with real data for direct material safety stock. An area which has not been as covered compared to safety stocks for finished goods.

Regarding the quality of this thesis. The progress and method have been continuously communicated with important stakeholders, taking into consideration any input that was received. The data has been gathered by company employees with knowledge of the ERP system and data experience, thus getting an extra level of confirmation. However, one weakness is that apart from confirming and discussing what data that should be used with stakeholders, the correctness of the data has not been evaluated, other than through interviews.

A different approach to the thesis could have been to focus less on the analytical side, and instead focus more on soft aspects. By interviewing more people at the case site that are working with planning today, a solution that they co-developed would be possible. The positive aspect of this approach would be the change management aspect, i.e. people tend to like something more if they have been involved during the development process. However, this could also result in an inferior end product, since the planners have not worked with safety stock before and might not know what they want, or what the academia suggests. Another risk with this approach would be that the tool would be too focused on the case site, and possibly not applicable to all the other sites.

Hopefully, the suggested framework will make it easier for supply planners to set a correct safety stock and maintain a smooth production. Enabling IKEA Industry to maintain low consumer prices and the supply planners to use their time for further stock analysis.

6.4 Further Research

Since this research has only focused on the site in Lubawa, and based the analysis on a few number of articles, a broader study could be made to see if the same conclusions can be reached. Such study would probably give a more exact result. In addition to this, taking more parameters into account would be both interesting for the case company and probably many others. One parameter that is seldom used in the literature, but often requested by companies, is the warehouse space factor. To take this into account in a method for safety stock calculations would probably be interesting for the industry.

Another parameter that has been studied is the cost of stock-out. However, no precise data exists in the case of IKEA industry. Ways to determine the actual site specific cost and ways to incorporate that in the model could help to both increase the understanding of why a safety stock should be kept, and allow for better safety stock estimations.

A wider scope including the suppliers could be a basis for future research too. Deciding the local optimal safety stock levels for each site is probably not the supply chain optimum. Looking at supplier relationships, incentives in contracts and the possibility of vendor managed inventory would all be possible studies that would benefit the case company. In this thesis, no contact has been made with the suppliers, but safety stock levels would definitely be affected if suppliers would be more involved.

For IKEA Industry, another aspect that would be of interest is how to collaborate better with IKEA, especially when it comes to forecasts. Today, the forecasts vary quite a lot from the actual orders, increasing the uncertainty, and thereby stock levels. Since both companies are part of the same group, internal tools to increase communication and awareness of how decisions affect the supply chain could be interesting to study.

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Appendices

Appendix A: Literature Search Protocol

Table 11. Literature search protocol.

Search phrase	**Number of hits/ whereof useful**	**Date**	**Reference**	**Data base**	**Content**	**Use(Yes/ No)**
Safety stock optimisation	199/1	2017-12-11	S. Klosterhalfen & S. Minner (2010) Safety stock optimisation in distribution systems: a comparison of two competing approaches, International Journal of Logistics Research and Applications, 13:2, 99-120, DOI: 10.1080/13675560903557866	EBSCO	Comparison of stochastic- and guaranteed-service approaches for safety stock optimisation.	No
Optimal Safety stocks	9/1	2018-1-16	Graves, S.C. (1996) A Multiechelon Inventory Model with Fixed Replenishment Intervals. *Management Science,* 42(1) pp 1-18.	Web of Science	A model for studying multiechelon systems with stochastic demand.	No
Safety Stock Level	849/2	2018-01-17	Collier, D.A., 1982. Aggregate Safety Stock Levels and Component Part Commonality. *Management science*, 28(11), pp.1296–1303.	Web of Science	Research on the relation between safety stock and component commonality.	Yes
Safety Stock Optimization	303/1		Neale and Willems: Managing Inventory in Supply Chains with Nonstationary Demand Interfaces 39(5), pp. 388-399,2009 INFORMS 399	Web of Science	Model for managing inventory in a supply chain with stochastic, nonstationary demand.	No
Safety Stock Method	613/2	2018-01-18	Kanet, J.J., Gorman, M.F. & Stosslein, M., 2010. Dynamic planned safety stocks in supply networks. *International Journal of Production Research*, 48(22), pp.6859–6880.	Web of Science	A model using MRP to do dynamic planned safety stocks.	Yes

Safety Stock Level	849/2		Boulaksil Y. (2016) Safety stock placement in supply chains with demand forecast updates. Operations Research Perspectives, 3, pp 27-31	Web of Scien ce	Research on where the stock should be placed in a supply chain.	No
Safety Stock Method	613/2		Schmidt, M., Hartmann, W. & Nyhuis, P., 2012. Simulation based comparison of safety-stock calculation methods. *CIRP Annals*, 61(1), pp.403–406.	Web of Scien ce	Comparison of nine safety stock methods with simulation as basis.	Yes
Produktions ekonomi	136/2	2018-01-27	Olhager, J., 2013. Produktionsekonomi: principer och metoder för utformning, styrning och utveckling av industriell produktion, Studentlitteratur.	Lovis a	overview of safety stock methods and product classifications	Yes
		2018-01-31	Mattson, S.-A., 2011. *Utvärdering av fem metoder för dimensionering av säkerhetslager med avseende på kapitalbindning*, Chalmers Tekniska Högskola: Logistik & Transport.		Comparison of five different safety stock methods.	Yes
Lagerstyrni ng	30/1	2018-02-03	Axsäter, S. (1991). Lagerstyrning. Lund: Studentlitteratur.	Lovis a	Inventory control	Yes
		2018-02-03	Oskarsson, B., Ekdahl, B. and Aronsson, H. (2013). Modern logistik. 4th ed. Stockholm: Liber.	Lovis a	Logistics	Yes
Safety Stock MRP	82/3	2018-02-06	Safety Stock versus Safety Time in MRP Controlled Production SystemsJ. A. Buzacott and J. G. Shanthikumar Management Science 199440:12, 1678-1689	Web of Scien ce	Short comparison of using safety stock and safety time in an MRP environment	No
Safety Stock MRP	82/3		Evaluation of safety stock methods in multilevel material requirements planning (MRP) systems; Zhao, X.; Lai, F.; Lee, TS Production Planning & Control); 2001 Vol. 12 Issue 8, p794-803, 10p.	Web of Scien ce	Safety stock methods in MRP	No
Safety Stock MRP	82/3		Caridi, Maria & Cigolini, Roberto. (2002). Managing safety and strategic stocks to improve materials requirements planning performance. Proceedings of The Institution of Mechanical Engineers Part B-journal of Engineering Manufacture - PROC INST MECH ENG B-J ENG MA. 216. 1061-1065.	Web of Scien ce	Methodology for strategic and safety stock in MRP	No

Safety Stock AND MRP	92/1		Kenneth R. Baker, Safety stocks and component commonality, Journal of Operations Management, Volume 6, Issue 1,1985, Pages 13-22, ISSN 0272-6963, https://doi.org/10.1016/0272-6963(85)90031-2. http://www.sciencedirect.com/science/article/pii/0272696385900312)	EBSCO	The affect on safety stock from components commonality	Yes

Appendix B: Simulation Result for all Methods

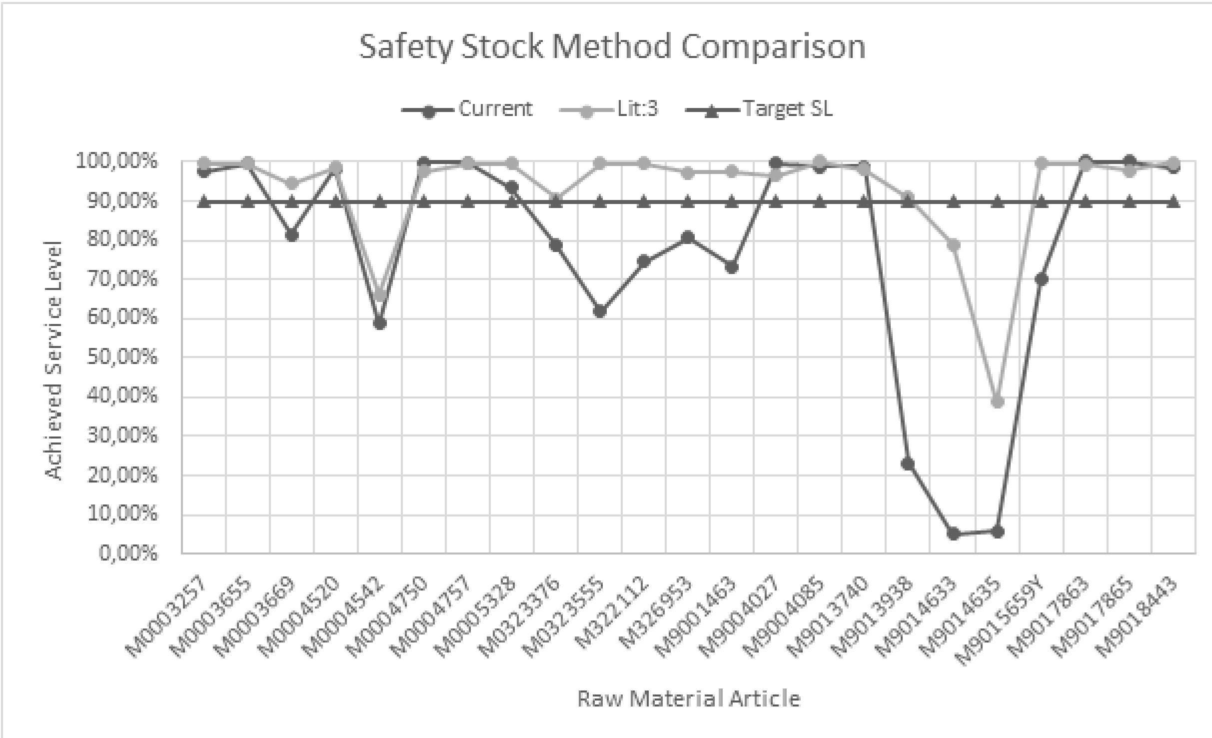


Figure 33. Simulation result for methods Lit:3.

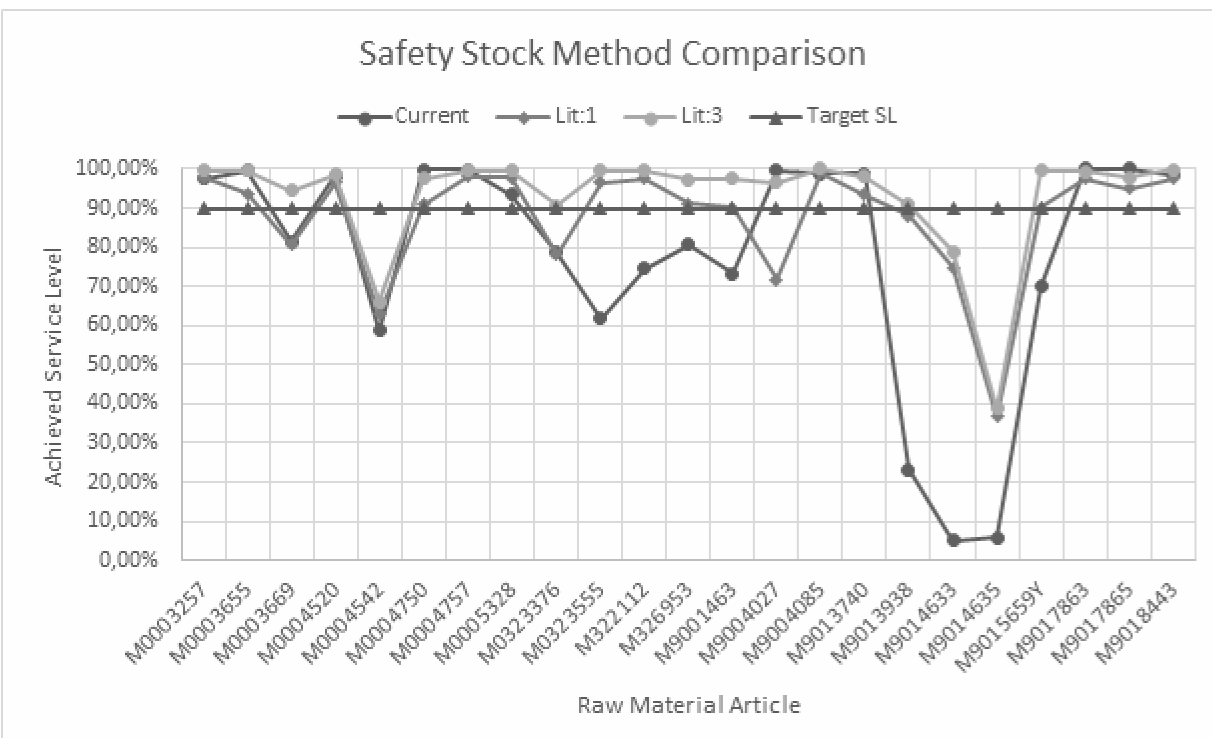


Figure 34. Simulation result for methods Lit:1 and Lit:3.

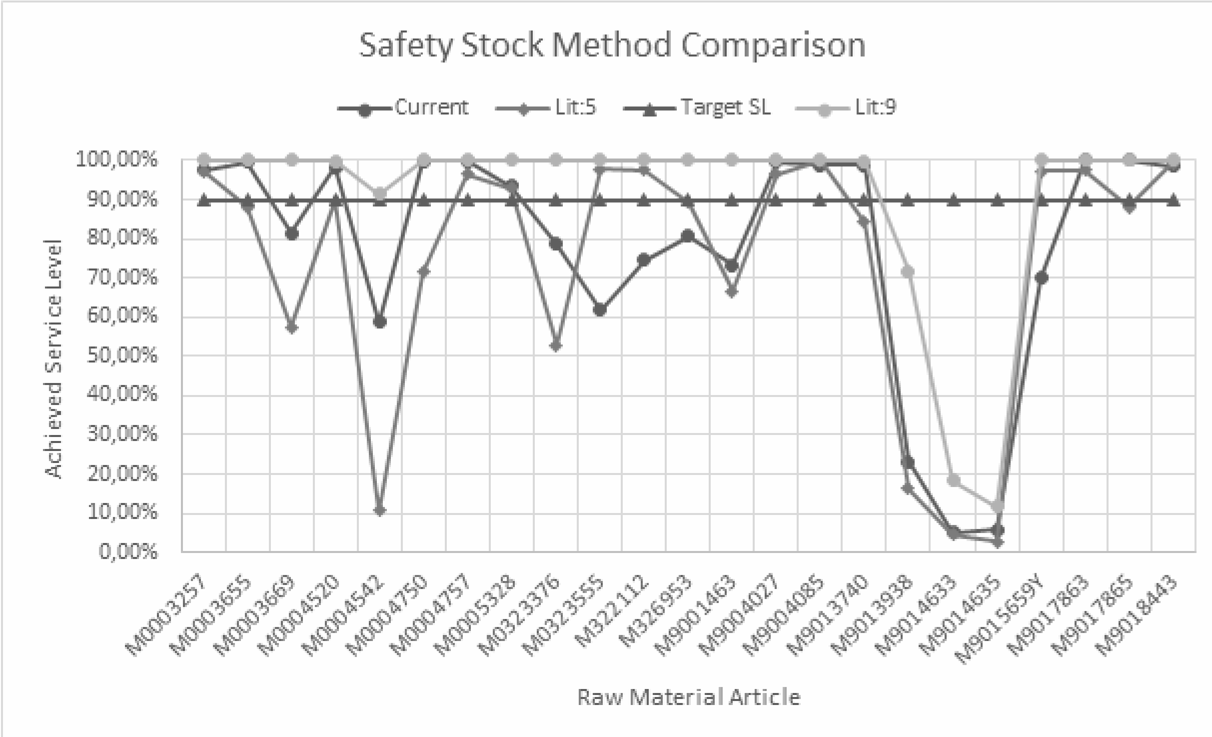


Figure 35. Simulation result for methods Lit:5 and Lit:9.

Appendix C: Framework User Manual

IKEA Industry

DIRECT MATERIAL SAFETY STOCK STANDARD

WHAT

Work instructions for calculating and setting safety stock and safety time levels for direct material. Please see [Poster link] for an overview.

WHY

To have the right amount of safety stock for each article.

HOW

By using the QlikView Source and by following the instructions below.

REVISION LOG

Date	Edition	Revised by	Summary of changes
2018-04-20	1.0	Oscar Gustavsson, Oskar Strömberg	Created

Doc. ID: Direct Material Safety stock standard
Edition: ??
Classification: ??

Publishing date: TBD
Author: Oscar Gustavsson, Oskar Strömberg
Owner: Gustaf Lilja

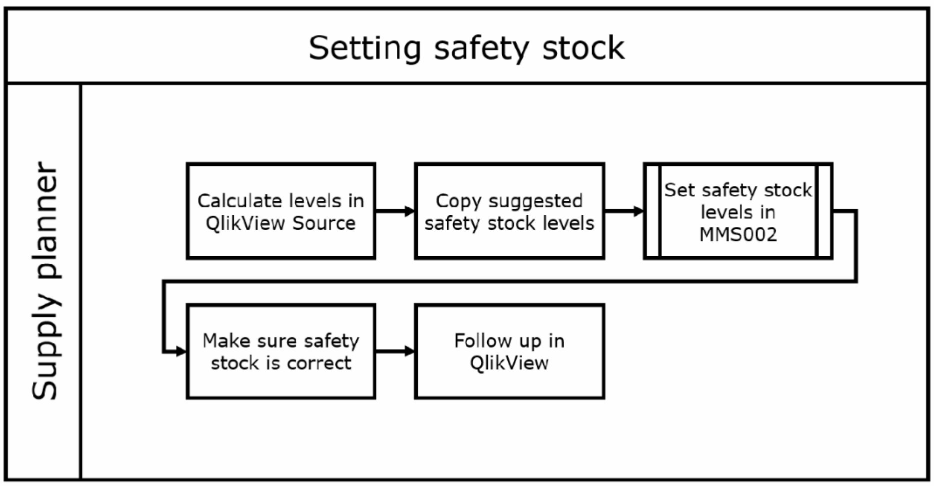
1 Definitions

Safety Stock – a level of extra stock that is maintained to mitigate risk of stockouts (shortfall in raw material or packaging) due to uncertainties in supply and demand.

Safety Time – an additional period of time which is added to the lead time when planning orders. The order is planned to arrive a period of time before it is needed, where this additional time is the safety time.

2 General information

2.1 Routine



2.2 Responsibility

The supply planner is responsible for this activity.

2.3 Output

Safety stock and safety time for raw material in MMS002.

3 Getting the data

The QlikView Source [link] is used to calculate safety stock and safety time. Go to the tab [Insert name].

3.1 Inputs

Before getting started there are two inputs needed:

1. Service level
2. A, B and C category percentages or a fixed number of days

Service level is a measurement that shows the probability of not getting a stockout due to insufficient raw material stock. It is possible to set two different service levels: service level for demand and service level for supply. Demand service level is how likely it is to manage changes in production with the safety stock, while the service level for supply is how likely it is to manage delivery changes, i.e. delays. By default, both are set according to the KPI's On Time Delivery (OTD) and Masterplan Adherence (MPA), currently 90%. However, these could be changed due to site-specific situations, or for certain product groups.

The product categorization is based on production frequency, i.e. raw material that are used in many production orders are rated A, while infrequently used raw material is rated C. The percentage of A, B, C articles can be changed to the left, by default it is: A: 80%, B: 15%, C: 5% of the total number of order lines. The classification affects how safety stock is calculated; a higher percentage of C-articles will lead to more products receiving less safety stock. Please see section 6.2 Information about classification, safety time, and safety stock, for a deeper explanation.

The second option is to override the ABC-classification with a fixed date. Raw materials that are used less frequently than the set date are automatically classified as a C-article, while the rest will be A-articles.

3.2 QlikView overview

On the first sheet you can filter for organizations, sites, and articles. Do the desired selection and the result will be displayed in the tables to the right. It is also possible to choose which interval the input data should be based on. If there are known changes in the future, the production forecast can also be included to give levels that are more accurate. For stable products, a longer interval could be used to get more accurate data, while for new products or products that have undergone changes where the past data does not reflect the future, the forecast is of higher importance. [Picture]

The first table shows articles, their category, current safety stock, and proposed safety stock and safety time. It is possible to sort for the articles that have the highest proposed changes of safety stock and safety time, compared to current levels. This is a good way to see potential areas of improvement. [Picture]

The second table compares current stock data with the proposed stock changes to see how it will affect inventory levels in number of units and stock value. [Picture]

The second tab includes a table showing the factors affecting the suggested safety stock and safety time. This is a good way to see what possible actions can be taken to get a lower suggested safety stock. [Picture]

3.3 Extract data

Once all inputs are set and the selection has been chosen, it is possible to either save it to Excel or keep the tab open for inputs into M3.

4 Setting safety stock and safety time in M3

Safety stock and safety time is set in MMS002.

The safety time is set at the tab planning parameters, see figure 1 below. Set the level suggested by QlikView. NOTE: If your site is currently using safety time in one way or another, the safety time needs to be adjusted based on the suggested value from QlikView. The suggested safety time is the intended number of days before production an order should arrive.

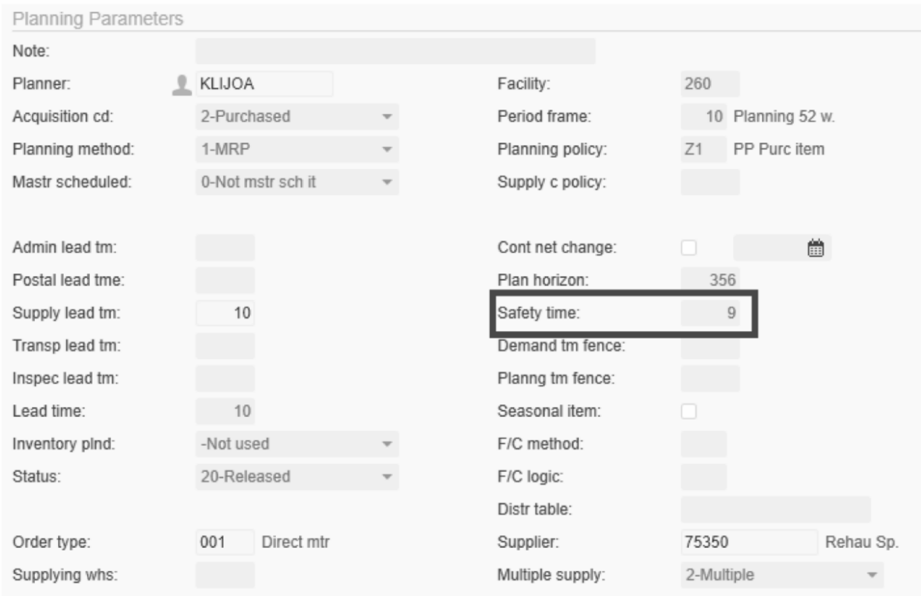


Figure 1. Planning parameters.

Safety stock is set in the subsequent tab Stock parameters. As noted in figure 2, the suggested safety stock from QlikView is inserted in the top left corner, while safety stock method should be set to 6-3rd party.

Figure 2. Stock parameters.

Press next and then you are done!

5 Follow up

Follow ups can be done in the third QlikView tab. This tab shows how low and high the stock levels have been during a certain period. The calculations considers both how long the stock have been outside of the stated levels, and by how much it has been either too high or too low. A higher percentage value means that the stock has been either further away from the desired level, or deviated for a longer time compared to one with a lower value. [Picture]

The calculations are done according to:

$$Max\ value: Safety\ Stock\ level\ in\ M3 + average\ production\ order + \sigma_{prod} * k_{90\%}$$
$$Min\ value: Safety\ stock\ level\ in\ M3$$
$$\%\ over\ max = \frac{\sum if\ over\ max\ value: \frac{value}{max\ value},\ else\ 0}{\#days\ in\ historic\ data\ period}$$
$$\%\ under\ mean = \frac{\sum if\ under\ min\ value: \frac{value}{min\ value},\ else\ 0}{\#days\ in\ historic\ data\ period}$$

6 Miscellaneous

6.1 Continuous work

Safety stock and safety time should be updated at least annually, or when any major production changes occur.

6.2 Information about classification, safety time, and safety stock

A-articles will always have both safety time and safety stock, while C-articles will only have safety time, see figure 3. This is due to the low frequency of the production orders. Raw material that is used seldom should not take up a fixed amount in storage at all times. B-articles is up for the planner to decide if they should have both safety time and safety stock, or only safety time. If this setup is not applicable to your site, the option fixed number of days is an alternative.

The safety stock and safety time calculations are done according to the following formulas:

$$Safety\ stock:\ safety\ factor * \sigma_{production} * \sqrt{Lead\ time}$$

$$Safety\ time: safety\ factor * \sigma_{Lead\ time}$$

Where the safety factor depends on the set service level.
$\sigma_{production} = Production\ quantity\ deviations$
$\sigma_{Lead\ time} = Leadtime\ delay\ deivations$

	Safety time	Safety stock
C-articles	$K * \sigma_{Lead\ time}$	0
A and B articles	$K * \sigma_{Lead\ time}$	$K * \sigma_{prod} * \sqrt{Lead\ time}$

Figure 3.Product classification impact on safety time and safety stock.

6.3 Frequently asked questions

Q: Why is the suggested safety stock and/or safety time so high/low?

A: The largest factor in the safety stock calculations is the production quantity deviations. If your site has high deviations in production, but you feel that you do not need to hedge against it, the safety stock can be decreased, either manually, or by choosing a lower service level.

Lead time deviations has the largest impact on safety time. If the suppliers are imprecise in their deliveries the safety time will go up. Please note, only late deliveries are considered. For suppliers that are regularly late the lead time should be changed.

Q: How often should I update safety stock and safety time in MMS002?

A: it is recommended that safety stock and safety time should be updated at least annually. If any major production changes occur during the year, an extra update should be considered.

Q: The QlikView shows another suggested safety stock today compared to yesterday, what has changed?

A: The QlikView updates daily when new data is available. Therefore, the information displayed day to day will vary. However, there is no need to update the safety stock in M3 frequently. Another reason could be due to a different interval was chosen.

Q: What is service level, and which level should I use?

A: There are two different service levels- service level for safety stock and service level for safety time. Service level for safety stock is a measurement that shows the probability of not getting a stockout due to lack of raw material, e.g. with a service level of 90% the material will be sufficient in 9 out of 10 times. The same reasoning applies for safety time, but with the difference that it measures the number of times the delivery will be on time.

By default both service levels are set to 90%. This is the advised level to manage the KPIs OTD and MPA. However, there will be site and material differences that could require adjustments to the default level.

Q: Which articles should I update first?

A: In the first tab in the QlikView the largest differences between the suggested safety stock and current safety stock can be found. Please start going through the articles with the highest deviation first, since these are the articles with the highest potential improvement

Q: The suggested safety stock is too high/low, should I update anyways?

A: Before updating to the suggested safety stock or safety time you should always consider if the value given is reasonable. The method does not cover all aspects, such as quality issues with the material. Please look at tab two to understand why the method has given a certain output and adjust the value to your local setting.

Q: Our site already has safety time in M3 due to planning when to place orders, can I still use safety time?

A: Yes, you should just add the suggested safety time to the already existing safety time in M3. Example: Today the safety time is set to 5 days in order to have time to place an order before it is needed. If the safety time is suggested to be 3 days the input into M3 should be: 5+3= 8 days.

Q: Why should the safety stock method be set to 6- 3rd party in M3. What implications does that have?

A: Setting it to method 6- 3rd party does not have any affect at all. It is just a way to distinguish articles that has safety time set according to the QlikView method from those that are manually inputted.

Appendix D: Framework Introduction Poster

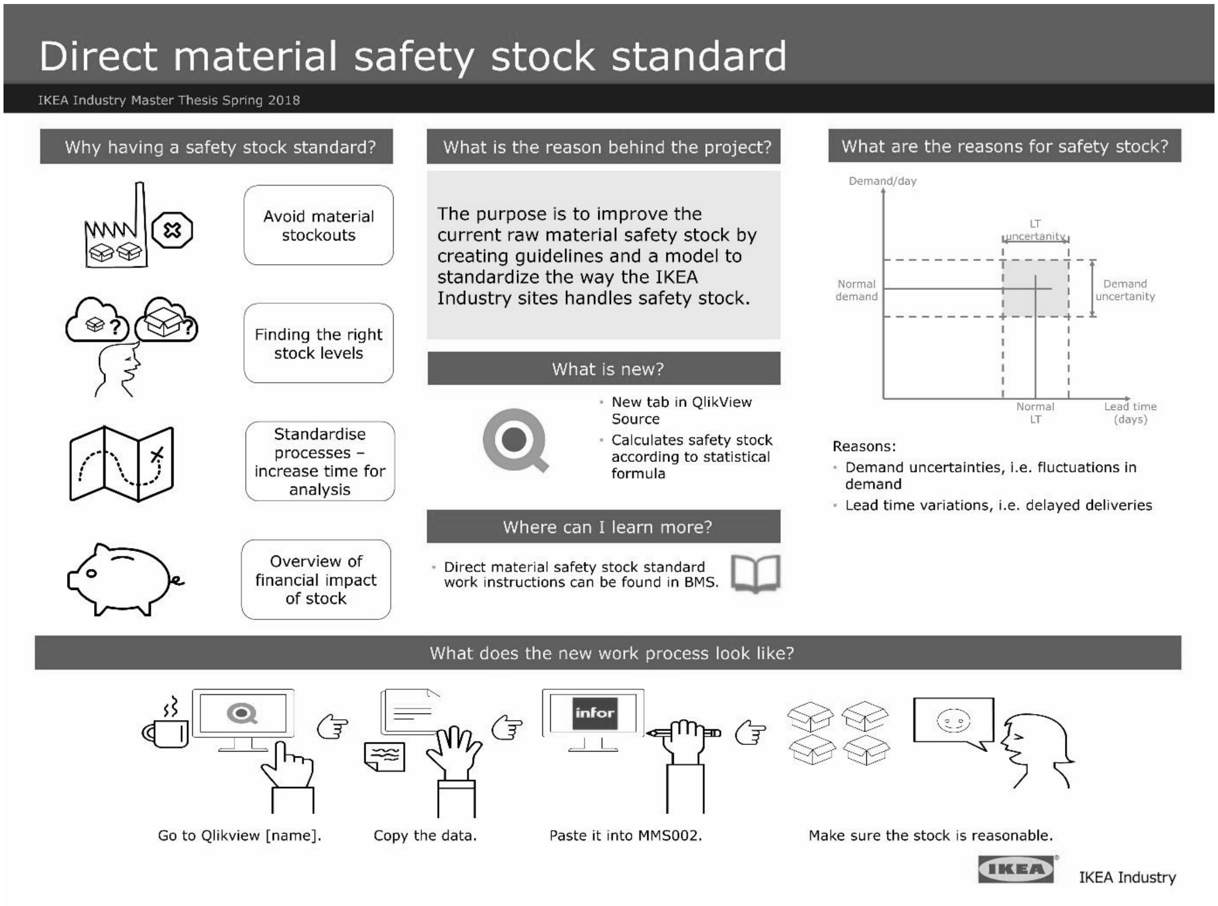


Figure 36. Poster with introduction to the safety stock framework.