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LUNDS UNIVERSITET
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Department of Industrial Management & Logistics
Production Management

Coordinated inventory control

- A case study on its performance compared to the current system at IKEA

Master's Thesis project 1002

Silvia Rasmusson and Björn Sunesson

Acknowledgement

This master's thesis is written as a final part of the Master of Science program in Industrial Engineering and Management at Lund University, Lund Institute of Technology. The project corresponds to 30 ECT credits and was performed during a period of 20 weeks in the summer and fall of 2009. The idea to perform a study on inventory control on IKEA came from Paul Björnsson, Process Leader for "Plan and Secure Capacity" at IKEA of Sweden. The suggestion to investigate the coordinated inventory control approach on IKEA's articles was developed together with Associate Professor Johan Marklund at the division of Production Management. These two have also been 0the supervisors during this thesis project.

Our aim with this master's thesis is to apply the knowledge acquired during the four previous years of study at the Master of Science program. It is our hope that the work done during the project will be valuable and used by IKEA to improve their supply chain.

We would like to thank our supervisors, the comments and feedback provided by these two mentors have been invaluable. We would also like to thank Birgitta Elmqvist for taking the time to answer all the questions we had, and providing us with the data needed to complete the project. We are also grateful to all those who took the time to give us introductory lectures on the supply chain, process mapping and culture of IKEA.

Abstract

Coordinated inventory management is not widely used among companies today. Not even modern companies, which should have resources and ability to always be in the forefront of technological developments, prioritizes models that in theory can provide substantial savings. This report illustrates that a slightly more advanced method to calculate the safety stock can increase the service accuracy and significantly reduce inventory costs.

The basic idea behind a coordinated inventory approach is to avoid sub optimization by optimizing jointly inventory locations that are dependent of each other, as opposed to optimizing each inventory alone. If information from one inventory is allowed to affect decisions in another, this can be used to together satisfy customers and reducing the total inventory.

The study started with locating a simple goods flow within IKEA. This goods flow contains only one distribution center and a number of retail stores. Representative articles that pass through both levels were then chosen. No consideration has been given to these articles flow prior to the shipping to the distribution center. For the selected articles, new coordinated reorder points have been calculated using an analytical multi echelon inventory model. This coordinated solution has been compared to IKEA's current solution (reorder points) by use of discrete event simulation.

The model used to optimize the system in the project has been previously tested on real case scenarios but only on low demand spare articles. This is thus the first time it has been used on end consumer pattern with high demand.

This project has resulted in evidence that the use of a coordinated inventory approach reduces inventory without decreasing service level. The largest relative reductions appear at the distribution center, while the mean inventory levels at the retail stores only decrease slightly.

Table of Contents

Table of Figures

Table of Tables

1 Company background

This chapter provides an introduction of the company IKEA. This will include a summary of the history as well as a simple description of the organization and the supply chain.

IKEA is one of the world's largest and most successful home furnishing companies. Good quality products at low prices is characterizing for the company. IKEA's core competences are designing, buying and selling home furnishing products. The company has outside suppliers who provide the manufacturing with the exception of Swedwood, which is an IKEA owned supplier of wooden products. The objective of the company and how it is reached can be summarized with its business idea and vision[1]:

Business idea: *"To offer a wide range of well designed, functional home furnishing products at prices so low that as many people as possible will be able to afford them."*

Vision: "*To create a better everyday life for the many people."*

[1] www.ikea.com, Business Idea

1.1 History

The name IKEA is an abbreviation of "Ingvar Kamprad Elmtaryd Agunnaryd" and in itself reveals part of the company history. Ingvar Kamprad grew up on the farm Elmtaryd in Agunnaryd and founded IKEA in 1943 when he was only 17 years old. Already then he was a true business man, selling pens and Christmas cards to neighbors and family ever since the age of 5. During the first few years he bought large quantities of anything he could get his hands on cheaply, and then sold it with a little profit per unit. He soon tried dealing with furniture and in 1952 IKEA announced that only furniture and other home furnishing items were to be sold. It did not take long until one of Kamprads closest employees thought of taking the legs off a table to simplify transportation and handling. IKEA was now the first furnishing company to introduce the "build-yourself"-concept widely used today.[2]

IKEA was a mail order company until 1958 when the first store opened in Älmhult. The second store opened in 1963 in Oslo. Switzerland was in 1973 the first country outside of Scandinavia to have an IKEA store.[3] Today, there are more than 300 IKEA stores, located in 37 different countries, and the number is constantly increasing.

IKEA employs over 127 000 people and is present in Europe, North America, Asia and Australia. In the fiscal year of 2008, 522 million customers[4] bought goods for 21,2 billion Euros.[5]

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[2] Torekull. 1998. *Historien om IKEA*
[3] Ibid
[4] Facts and Figures, 2008
[5] Ibid

1.2 Organization

The IKEA sphere consists of three main organizational groups. The groups are the *Ingka Holding BV, IKEA Holding*, both owned by The Stichting Ingka Foundation, which is located in the Netherlands, and *Ikano Holding,* all of which in turn own several companies each. The reason for the ownership through foundations and the complex structure with firms throughout the world is mainly to guarantee IKEA's long term survival by not giving all the decisive power to a few people.[6]

Figure 1: IKEA organizational chart

The *Ingka Holding BV* (called the blue group within IKEA) is the organization that owns and operates the majority of the retail stores around the world. It is also the branch responsible for designing and developing new products and is responsible for the supply chain's operations.[7] The blue group has its head quarters in the Netherlands and since September 9th 2009, the CEO is Mikael Ohlsson

IKEA Holding (the red group) in Luxemburg owns about 70 firms, including IKEA Systems BV. IKEA Systems BV owns the concept of IKEA and all stores are therefore its franchise takers. All retail stores, including the ones that are not run by The Ingka Holding BV, pay 3% of their turnover as franchise fee.[8]

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[6] Torekull. 1998. *Historien om IKEA*

[7] Pettersson. 2009. Älmhult

[8] Bränström. 2004. *Blått, grön och rött styr*

The third group, *Ikano Holding* (the green group) is owned by Ingvar Kamprad's three sons and is therefore the only group still owned by the family. The businesses within Ikano Holding are diversified, including real estate, insurance, investment management and banking.[9]

This master thesis concerns mainly the supply chain part of the Ingka Holding BV.

1.3 Supply chain

There are three ways in which customers purchase products from IKEA. This section will outline the different ways.

Products can be bought at retail stores, ordered by phone or ordered over the internet. In the latter two cases, the products are delivered directly to the customer's home, from a customer distribution centre and in most cases via a local hub[10]. Customers have time to browse through the catalog, electronic or paper, before they order. When customers walk through the stores on the other hand, it is important that products are available and visible, or the customer will not buy them. Ordering via the internet or the phone already shows that the customer is willing to wait for the product and an extra waiting time due to shortages will not decrease the customer success as much. Customer success is defined as the customers who are satisfied with the purchase in terms of price, availability and service.

At the time of writing, there are two flows of products within IKEA. Some of the articles are replenished to stores from distribution centers and the others are delivered directly to stores from suppliers. Direct deliveries minimize the handling costs as well as transportation cost, but on the other hand generally drive up the stock levels.

Articles delivered through distribution centers are mainly divided into two flows, high and low flow. The high flow distribution centers are either used for storage

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[9] Pettersson. 2009. Älmhult

[10] Ericsson. 2009. Älmhult

or as transfer centers where articles are repacked and shipped to retail stores. There is usually not only one but several distribution centers, called a DCG (Distribution Center Group), supplying a geographically limited market. Lead times from suppliers to distribution centers and stores are generally longer than the lead times from distribution centers to retail stores. Lead times from suppliers are normally a few weeks while lead times from distribution centers are only a few days.[11]

Low flow articles are articles subject to low volume demand, and these articles are not stored in the local distribution centers across the world. Instead, there are only a small number of distribution centers, each one supplying its entire market with low flow articles. For the European market, there is a low flow distribution center in Dortmund. This is a relatively new attempt to benefit from the created economy of scales and therefore reduced costs. The idea is to avoid keeping many small inventories across distribution centers. Transportation costs are higher, but the savings are thought to be even greater. For some local suppliers who are unable to produce enough material to fill an entire truckload each order cycle, there are consolidation points where deliveries from different suppliers are combined into one delivery to achieve as full truckloads as possible.[12]

[11] Ericsson. 2009. Älmhult
[12] Ibid

The entire supply chain of IKEA is illustrated in Figure 2. This master thesis will only concern high flow products that pass through a distribution center.

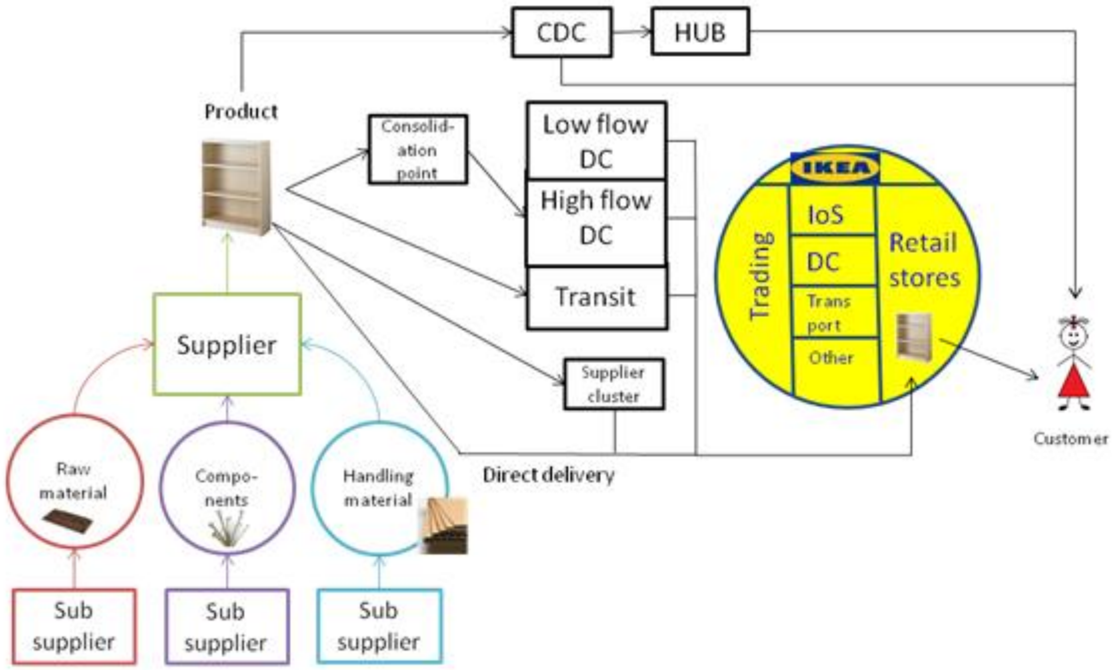


Figure 2: IKEA supply chain

2 Problem formulation

In this chapter the problem formulation of the project is discussed. The main and secondary objectives are presented as well as the target group and the delimitations. Finally, a report outline is provided.

IKEA has identified that the inventory levels kept at retail stores and distribution centers throughout the company are generally high. This will create unnecessarily high holding costs, which will reduce the profitability of IKEA. High inventory levels are especially expensive when articles are removed from the range of products, hence the remaining products will be disposed of and not profited on.

Nearly all inventories systems are set to optimize the stock level at each installation, without regard to other installations throughout the supply chain. All inventories are controlled independently and safety stocks will be large enough to cover uncertainties from the next level of demand. The different levels will not benefit from information from the other actors and the system as a whole will only be sub optimized. In the case of IKEA, the service level requirement is the same for both retail stores and the distribution center. With this system, it is likely that the central warehouse keeps a non-optimal amount of stock. The service level that is experienced by customers is the important one. It does not matter what service level the retail stores experience from the distribution centre, as long as the customers do not experience shortages.

This master's thesis will give IKEA a chance to see how a coordinated inventory control system will affect the company. It will not provide any exact or detailed recommendations on how to implement the coordination approach into the current ERP-system, but instead show a possible next step in the development of the control system.

2.1 Objectives

The purpose of this project is to investigate how a model for controlling a multi level inventory system can be used to calculate reorder points for IKEA's distribution centers and retail stores. Furthermore, the project will, by simulation in the discrete event simulation software Extend, analyze how much the inventories could be reduced if a coordinated inventory control method is implemented, instead of the uncoordinated control system used today.

The analysis will be conducted using a sample of articles and the corresponding real case data from a geographically limited area. In this study, the goods flow chosen is the simplest possible multi level case: one distribution center and a number of retail stores. All articles included are replenished from that single distribution center. The chosen articles are taken from different price, frequency and service level categories. This means that even though only a fraction of the total number of articles is included, the results of the project should be representative for a larger number of other articles.

2.1.1 Secondary objective

In addition to investigating how well a multi level inventory system will work, this project will also evaluate how well the service level measurement performed by IKEA today coincides with a theoretical definition of the service level called fill rate. This is defined as the proportion of total demand immediately satisfied from stock on hand.

2.2 Delimitations

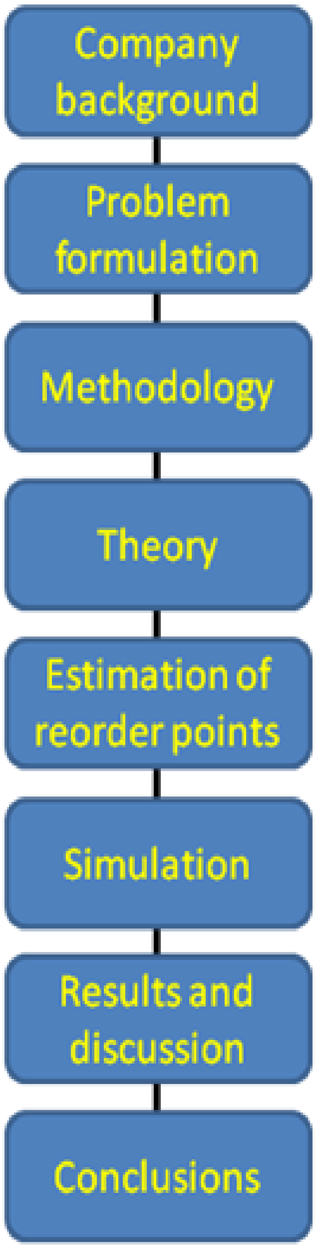
The geographical area chosen in this case study is the distribution center and the seventeen retail stores in a geographically limited market. Common for all the articles is that they are delivered to retail stores through distribution centers, as opposed to direct deliveries from suppliers. All articles are also found in the self serve range of products. The project will exclude articles introduced to and removed from the product range during the year that is studied, since these articles will have a misleading impact on the overall results. No low flow articles will be studied, as these are, as stated before, supplied from a distribution center common for the entire European market.

2.3 Target group

The target group of this master's thesis is divided in two different categories, IKEA and our fellow students at the university, especially those studying inventory management and future master's thesis authors. The division of Production Management at the Department of Industrial Management & Logistics at Lund University, Faculty of Engineering also has an interest in the outcome of the project. At IKEA, the report will mainly be used as a documented illustration and evaluation of possible stock reductions of implementing a coordinated inventory control system and how this will affect the service levels. Thus, the project will be more aimed towards the employees working with the supply chain.

2.4 Report outline

The report is divided into the following chapters:



Chapter 1 – Company background

This chapter provides a background to IKEA as a company, with main focus on the supply chain.

Chapter 2 – Problem formulation

The second chapter presents the objectives, purpose and target group for this master's thesis.

Chapter 3 – Methodology

The methodological choices made in the study are presented in this chapter as well as the procedure of work. The validity, reliability and objectivity of the study are also discussed.

Chapter 4 – Theoretical frame of reference

In this chapter the theoretical base relevant to this project are explained to the reader.

Chapter 5 – Estimation of reorder points

The fifth chapter introduces the method used to calculate reorder points according to a coordinated system, as well as the estimations made for the current system.

Chapter 6 – Simulation

The simulation model used to validate the coordinated approach is presented in this chapter, as well as the assumptions made while building it.

Chapter 7 and 8– Results and discussion

These chapters present the results of this master's thesis and displays relevant graphs and diagrams. It also discusses the results.

Chapter 9 – Conclusions

In this chapter, the conclusions drawn from the project are presented. Finally, recommendations on the use of this master's thesis are given. Suggestions on how to expand the study and improve results is also provided.

3 Methodology

This chapter describes the procedure of the project as well as definitions and explanations of the most important methodological terms and the methodological choices made in the project.

3.1 Procedure

During the course of this project, the model seen in Figure 3 has been used as a guideline on how to organize the work.

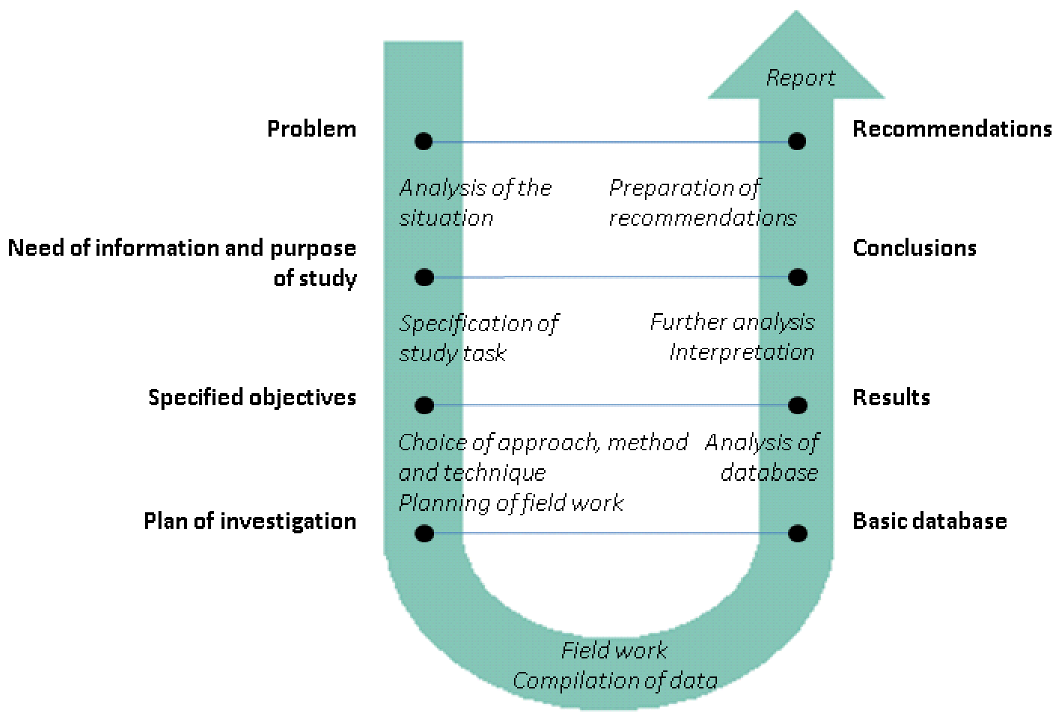


Figure 3: Routine of a typical project[13]

As seen, the model is shaped like a U, in a way that connects the preparations to the field work with the results and analysis of the results. Below, the work performed during this master thesis is presented, and related to the different steps in the model above.

[13] Lekvall & Wahlbin. 2001. *Information för marknadsföringsbeslut*, pp. 183-191

The problem identified by IKEA is that the inventory levels kept at retail stores and in distribution centres presently are too high. Since reported sales increase yearly this is a problem that is expected to increase. IKEA wants to constantly investigate better approaches for inventory control in order to lower stock levels while keeping or improving customer satisfaction.

3.1.1 Analysis of the situation

An introduction to the company's supply chain was first provided by IKEA to give the authors of this paper the suitable background before examining the possibilities to improve the situation of today. The idea to investigate how a coordinated inventory control approach might improve the current system was suggested by the authors and accepted by the supervisor at IKEA.

3.1.2 Specification of study task

Discussions with the supervisor at the university and the supervisor at IKEA resulted in the specified objective to study an existing model for coordination of inventory control and investigate possible gains if implemented at IKEA. This investigation is going to be done by using historical data and comparing the results to the current inventory system. The project should also result in a simulation model in which both the current and the proposed systems can be tested. The purpose of the simulations is to analyze the effects of a possible implementation. The specified objective and delimitations of the project resulted in a Project Specification that was presented to all parties involved. The objective is found in chapter 2 in this report.

3.1.3 Choice of approach, method and technique

Once the specified objective was set, the authors studied and decided upon methodological choices to be made. The study and decisions resulted in this present chapter (Chapter 3). A time plan was created as well, to ensure the report was finished within the given time frame for the master's thesis. In this step, the relevant theoretical background was acquired and studied, see Chapter 4. The theoretical study of the technique going to be used also resulted in a list of data needed from IKEA in order to proceed with the project.

3.1.4 Field work

The field of work consisted of three main steps:

1. Sorting and processing the data provided by IKEA
2. Determine reorder points according to the chosen method for coordinated inventory control
3. Simulating IKEA's inventory system with the new approach, as well as with the present one and extracting the results.

The details on how the steps above are done are thoroughly described in chapters 5 and 6. The output from the simulation (step 3 above) constitutes the basic database.

3.1.5 Analysis of data base

The basic database of the field of work was then compiled and from that, conclusions were drawn. The results should correspond to the stated Project Specification. The results are presented in Chapter 7.

3.1.6 Interpretation

There is a large number of output data that needs to be sorted and processed in an understandable way to draw conclusions and for the reader to understand the outcome of the study. It is worth mentioning that the quantitative approach throughout the master's thesis leaves little room for interpretation. A discussion of the results is done together with its introduction in Chapter 7.

3.1.7 Preparation of recommendations

The recommendation to IKEA can be found in Chapter 9, which summarizes and concludes the project.

3.2 Research approach

The choice of research approach will mainly depend on the relationship between theory and empirics in the project. It is common to define the research approach as either inductive or hypothetical-deductive.[14]

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[14] Wallén. 1996. *Vetenskapsteori och forskningsmetodik*, pp.47-48

3.2.1 Concept description

In an *inductive* approach a study and analysis of reality is performed and forms a base for a generalized and theoretical conclusion. It is important that the data is gathered unconditionally. The inductive approach is often criticized because the gathering of information and the choice of studying certain phenomenon must build on some kind of background theory which makes the gathering of data no longer unconditional.[15]

The (*hypothetical-)deductive* approach starts with theoretical studies which are then applied to a real empirical case and conclusions are drawn based on the underlying theory. Clearly, the existing theory plays a more important role in the deductive approach. A hypothesis is built on existing theory, and then tested in reality. The conclusion will be either to reject or accept the hypothesis.[16]

An *abductive* approach is neither pure inductive nor pure deductive, but a mixture of both. The aim is to find the source or cause for an occurred phenomena, using existing theory.[17]

3.2.2 The research approach used in this project

Due to the nature of this master thesis it is suitable to use a deductive approach. The objective is to use existing theory and models to improve IKEA's inventory control system. The theory is used to determine reorder points with a coordinated approach at IKEA. For obvious reasons the implementation cannot be done in reality due to the early stage of the study. Simulation of the inventory system will in this project work as a testbed for the solution.

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[15] Wallén. 1996. *Vetenskapsteori och forskningsmetodik*, pp.47-48

[16] Ibid. pp. 47-48

[17] Ibid. pp. 47-48

3.3 Methodology

Depending of the objective of the project there are different methodology approaches to choose from. The authors of this paper have searched for approaches that might be applicable for this specific case and found the major ones to be: survey, case study, experiment, action research and operations research modeling.

3.3.1 Survey

A *survey* is done by systematically mapping a phenomenon with the objective to describe it. The mapping is done by asking questions to a number of people. The questions must be the same to everyone participating in the survey. The selection of participants can be either random, stratified (picking a representative number of the population from all categories included in the survey) or complete (all individuals). The objective of a survey is often to give a generalized picture of a broad issue that might be applied to other cases.[18]

3.3.2 Case study

A *case study* aims to describe a specific object or phenomenon. The difference between a case study and a survey is that the former describes the issue more deeply. Interviews and other methods of gathering information can be flexible. Questions asked during interviews must not be the same to all participants, as opposed to a survey. The results of the case study are not necessarily applicable to other general cases. It enables deep understanding of the studied object phenomenon. There are three major methods of data gathering[19]:

- Interviews
- Observations
- Archive analysis

[18] Höst et al. 2009. *Att genomföra examensarbete*, pp. 30-33
[19] Ibid, pp. 33-35

3.3.3 Experiment

An *experiment* aims to find the causality between input and output parameters. The design of the experiment is fixed, that is, the procedure is pre-defined and cannot be changed during the process. The first step of an experiment is to define a clear objective and from that formulate a hypothesis, i.e. an assumption of what is going to be studied. The next step is to identify the parameters that might influence the studied phenomenon (input parameters) and what the resulting parameters (output) are. The design of the study is then set up, the experiment is executed and the hypothesis is either rejected or accepted[20].

3.3.4 Action research

An *action research* aims towards improving something at the same time as studying it. The first step is to observe a situation or phenomenon in order to identify and define a problem that is going to be solved. A proposal of how to solve the problem is then designed and executed. It is important to evaluate the solution and analyze how well it works. If the solution is not good enough it might be necessary to make a new proposal to improve it. This is repeated until a satisfying solution is reached. The method can be summarized with Plan-Execute-Study-Learn[21].

3.3.5 Operations research modeling

Typical for a project where an analytical model is applied to a real case scenario and is based on quantitative techniques is called *operations research (OR) modeling*. The working process often follows six major phases[22]:

1. Define the problem of interest and gather relevant data
2. Formulate a mathematical model to represent the problem
3. Develop a computer-based procedure for deriving solutions to the problem from the model
4. Test the model and refine it as needed
5. Prepare for ongoing application of the model as prescribed by management
6. Implement

[20] Höst et al. 2009. *Att genomföra examensarbete*, pp. 36-39
[21] Ibid, pp. 39-41
[22] Hillier. 2005. *Introduction to operations research*, p. 8

3.3.6 Methodological approach for the project

Considering the purpose of this paper, the most suitable methodological approach is to use an operations research modeling. The building of a mathematical model (phase 2 in the OR modeling) is not done by the authors, but instead an already existing model for optimizing multi echelon inventories is used. Part of the computer-based procedure used for finding the solution for the problem already exists as well. The authors have developed the simulation model in the software Extend for conducting the testing and evaluating the alternative solution as it is today (phase 3). The testing is done by using the simulation model that is built to best represent the goods flow (phase 4). This master's thesis does not go through phase 5 and 6 as it is only a pre-study. The preparation for an ongoing application and the implementation will at the end of the project be left for management to decide whether it should be done or not.

This master's thesis is a case study considering the procedure of investigating a geographically limited market and a sample of articles. The method used in the case study to collect the relevant figures is through existing archived data. A survey for getting the data needed for the study could have been used but due to the availability through extractions of data from IKEA's ERP system this was not necessary.

3.4 Method of analysis

A study can be either qualitative, quantitative or, as in most cases, a mix between the two. In this section both aspects will be described, and the chosen method motivated.

3.4.1 Quantitative approach

In a quantitative study the information gathered and used is such that it can be measured and described in numbers. The information can thus be processed using statistical methods, and the results can often be used in generalizations.[23]

Advantages with a quantitative approach are for example:[24]

- Quantitative data is suitable for statistical methods, which are firmly based on mathematical theories. This gives the study a scientific basis.
- Similarly, tests of significance on the data can give the study a higher credibility.
- Quantitative data is easy to measure and analyze, and thus the results of the study can easily be investigated by others.

Disadvantages with the method include:[25]

- If the quality of the input is low, the quality of the output will be low.
- With computers' aid, it is easy to include too many parameters in the study, increasing the complexity of it and possibly making it difficult to understand and overview.

3.4.2 Qualitative approach

A qualitative study will use more detailed information compared to a quantitative one. The data used in a qualitative study will consist of descriptions or visual images, both of which require methods of analysis such as sorting and categorizing. The collection of qualitative data can be rather complex, some examples of means for this are interviews, literature reviews, observations and questionnaires. [26] This type of approach is suitable for non-numerical studies.

[23] Denscombe. 2009. *Forskningshandbok*, p. 327
[24] Ibid, p. 364
[25] Ibid, pp. 364-365
[26] Ibid, pp. 367-368

As for the quantitative approach, there are advantages and disadvantages with this approach. Some advantages are: [27]

- The data analyzed will be detailed and rich on information. This is suitable for studies of for example social situations.
- The analysis has room for contradictions. It is not unusual that different people interviewed have different views on matters. A qualitative approach handles this better than a quantitative.
- The possibility of more than one "correct" explanation exists. In the case of quantitative studies, this is often not the case.

The disadvantages with this approach can be: [28]

- The study can be difficult to apply to the general case, due to the relative small number of objects studied.
- The interpretation of the data can be very dependent on the researcher's experiences, opinions and beliefs.
- The analysis can be time consuming. As opposed to the computer based organization of quantitative data, there is not a fast way to organize qualitative data.

3.4.3 Approach of this study

This study aims to compare the current system for calculating reorder points with a better coordinated system. Most of the data collected for this paper, such as weekly sales and lead times, will be quantitative. Furthermore, the results of the paper will be based on the inventory levels and service levels, both of which are quantitative measures. As such, it is natural that the method of analysis in this paper will be a quantitative modeling approach.

3.5 Sources

During the course of a master thesis, a number of different sources of information are used. This chapter describes these different sources and motivates their use in this project.

[27] Denscombe. 2009. *Forskningshandbok*, p. 398
[28] Ibid, pp. 399-401

3.5.1 Primary and secondary sources

Information gathered may come from one of two kinds of sources; primary or secondary sources. Primary sources are for example interviews or enquiries, in which the information needed is obtained for the sole purpose of the current study.[29] Secondary sources, on the other hand, originate for a purpose other than for the current study. This can be general literature on the subject or presentations held for several other people as well. To obtain useful secondary data it is imperative to be aware of the fact that the information might be aimed towards a different target group and as such might be biased.[30]

3.5.2 Data collection

Gathering data is a vital part of any master thesis. The most common methods of acquiring data are described below:

- *Literature:* A literature review is a way of investigating previously written material on the subject studied and, if included in the report, giving the reader a better background knowledge on the subject. Different sources of literature can be books, articles, encyclopedias and internet pages.[31]
- *Interviews:* An interview is a session during which questions are given to, and answered by, interviewees. Three different kinds of interviews can be identified depending on the amount of structure used during the interview:[32]
    - *Structured interview:* the interviewer has decided which questions to ask beforehand, all interviewees are asked the same questions, and are limited to fixed responses. Since the answers are fixed, they can be compared more easily, which basically makes this a survey performed orally.
    - *Open interview:* the interviewer is guided by an interview guide created beforehand. However, the order of the questions can vary between interviewees, and the interviewees are also given the possibility of providing more detailed answers.

[29] Björlund, Paulsson. 2003. *Seminarieboken,* p. 67
[30] Ibid, p. 68
[31] Höst et al. 2009. *Att genomföra examensarbete,* pp. 89-92
[32] Björlund, Paulsson. 2003. *Seminarieboken,* p. 67

- *Semi structured interview:* as its name implies, a mix between a structured and an open interview. Some questions are predetermined, and some are more open. It is however imperative that the predetermined questions are asked in the same order and in the same context to each interviewee, to keep the comparability between the answers.

- *Survey:* When the opinions and perceptions are to be collected from a large number of people, interviews might take too long. Instead, a survey can be conducted. A survey is a questionnaire, most often with predefined answers, that is given to a number of people.[33]
- *Observations:* When a phenomenon is studied, the best way of capturing the relevant information is to directly observe it while it happens. This can be done by either observing the phenomenon directly, or by using technical equipment to gather relevant data. An observer can have different roles in the interaction with the studied phenomenon. If the role of the observer is known, there is a risk that the observed phenomenon is affected by this.[34]
- *Data collected by others:* Occasionally, it is necessary to use data that has been collected by others. The reason for this might be that there is not enough time to collect the data, or that it is the only information possible to receive. This kind of data is a secondary source, which makes it important to analyze the received information. There are four different kinds of data collected by other, as follows[35]:
    - *Processed material:* Data that has been collected and processed in a scientific context.
    - *Available statistics:* This is data that has been collected and processed. No conclusions have been drawn from the analysis though.
    - *Registry data:* This kind of data is available in raw format.
    - *Archive data:* This data is not systemized as data. Items such as protocols and letter correspondence are archive data.

[33] Björlund, Paulsson. 2003. *Seminarieboken,* p. 68.
[34] Ibid, p. 69.
[35] Höst et al. 2009. *Att genomföra examensarbete*, p. 98.

- *Experiment:* Experiments are similar to observations, with the exception that the variables affecting the studied subject are controllable. This is also the biggest advantage with the method, together with the possibility to repeat the experiment numerous times. However, when conducting experiments it might be difficult to create similar conditions as in reality.[36]

3.5.3 Sources used for the project

During this project, the main methods of information gathering have been literature and receiving data from the ERP-system used by IKEA. The literature used has been scientific articles, text books on statistics and inventory control as well as internal documents of IKEA. Common for all the sources used is that they are secondary sources.

The introduction and explanation of the analytical model has been provided by Johan Marklund, who is regarded as a reliable primary source. All interviews performed at IKEA are also of primary nature.

3.5.3.1 Criticism of sources

The data collected from IKEA's ERP-system is a secondary source and the authors of this paper have no possibilities to verify its accuracy. This is not seen as an issue as the system stores registry data, and since the data is not processed, it is not tampered with in any way. Furthermore, it lies within the interest of IKEA to provide data that is as accurate as possible. Unfortunately the available data for demand is not exactly the type required, as the required data is exact demand and the available consists of weekly sales.

When it comes to the literature used in the project, the articles used are all published in well respected international journals that require a high scientific standard of the articles published. When using text books and electronic sources such as internet pages to define words and expressions, the authors possess the knowledge to evaluate the relevancy and accuracy of the sources.

[36] Björlund, Paulsson. 2003. *Seminarieboken,* p. 69

3.6 Tools

The process of developing an inventory control system for IKEA requires tools for the following

- Handle, sort and process data
- Calculate reorder points
- Estimate statistical distribution for demand
- Simulate current and proposed inventory system

The data handling and calculation of reorder points are done with the help of Microsoft Office Excel 2007. The simulation part of this project is executed using the software Extend.

3.7 Credibility

The credibility of this master thesis will be looked upon from three perspectives: validity, reliability and objectivity. How these are assured will be presented after a brief description of their meanings.

3.7.1 Validity

The general definition of *validity* is a measure of the extent to which what is measured really is what is supposed to be measured. To increase the validity of a study, the problem should be seen from several different perspectives.[37]

After working for a long time developing a model and looking at details, there is a great risk of losing perspective. It can therefore be a good idea to, at the end of the project, take a step back and look at the overall picture to see if the results are reasonable and to make sure no major error have occurred. This is preferably done together with someone who has not participated building the model but who understands the problem, to have an objective point of view. Fatal errors like dimensions consistency when using mathematical expressions must be avoided.[38]

[37] Björlund, Paulsson. 2003. *Seminarieboken,* pp. 59-60
[38] Höst et al. 2009. *Att genomföra examensarbete*, p. 42.

An increased validity is also given by changing input parameters and controlling if the model behaves as expected. This is specially revealing if the parameters are extreme of both maximum and minimum values. Another way to enhance validity is to do a retrospective test, which means using historical data as input parameter. The results are then compared to what actually happened and it reveals if the model would give better results than reality. It can also reveal if the model is correct. The drawback of using retrospective testing is that the results given from the data used to create the model (historical) do not necessarily give good results for the future.[39]

3.7.1.1 Validity in the project

The objective gives a clear definition of what is supposed to be measured and because of the quantitative procedure and the results being in numerical measurements, little space is left for measuring errors. The analytical model used in the project is developed and tested by professionals in the area and can therefore be regarded as fully valid.

In the cases where the authors of this paper find it necessary to make specific tests of validity, this will be clearly described in the relevant sections of the paper. Comments will also be made where assumptions that might lower the validity have been made.

The quality of input parameters could have been better if the historical data had been available for more than one year as well as daily sales data. IKEA's ERP-system, from which the data was taken, only stores data for the past year. In order to calculate the reorder points according to a coordinated approach, some considerable assumptions and approximations had to be done. Some real data had to be adapted to suit the input parameters necessary to run the model used for the calculations. One example is order quantities. The model requires fixed order quantities, but IKEA is not always restricted to fix orders. This will be further described in section 5.2.3.

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[39] Hillier & Lieberman. 2005. *Introduction to operations research*, p. 18

Because of the complexity of IKEA´s goods flow, simplifications have been made to enable simulation. There are factors like season variation and special campaigns that change the flow over time and that would take too much effort, if even possible, to be looked upon. The simulation model assumes a steady state situation statistical distribution of demand which does not change over time.

3.7.2 Reliability

A study that renders the same results when performed multiple times has a high *reliability*.[40] The reliability of a study can be ensured by being as accurate as possible when gathering information. It is also advisable to document the procedures used to obtain the data, and let a tutor or colleague verify it.[41]

3.7.2.1 Reliability in the project

Every assumption and delimitation has been documented. This will increase the reliability of the project since it makes sure that others can verify the results by using the same input data. Making other assumptions would possibly change the results considerably. The major flaws in the reliability concern the input parameters and the simulation of the inventory system. Gathering data from another period than for this paper might change the results, since the customer demand pattern changes over time, as does the range of products, goods flow, service target levels, lead times and so on. The change in one of those parameters does not likely to affect the results significantly, and a substantial change in many is not likely to occur. The reliability in the project is therefore regarded as high.

3.7.3 Objectivity

Objectivity is a measure of to what extent the authors' values affect the results of the study. In order to increase the objectivity of a study, it is important that every choice made is clearly explained and motivated. In this way, the reader can form his own opinions regarding these choices. There are three main guidelines to follow when using outside sources: no factual errors, no distorted information and avoidance of words like "she states" or "he realizes".[42]

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[40] Björlund, Paulsson. 2003. Seminarieboken, pp. 59-60
[41] Höst et al. 2009. *Att genomföra examensarbete*, pp. 41-42
[42] Björlund, Paulsson. 2003. *Seminarieboken,* pp. 59-62

3.7.3.1 Objectivity in the project

The objectivity of the project depends on to what degree the authors' interpretations and values have affected the study. The objectivity has been improved by ensuring that every choice made is based on facts which follow the nature of a quantitative project. The fact that all data come from IKEA's EPR-system only enhances the objectivity, since the data consist of historical numbers, and is thus not tampered with. There is little room for the authors' interpretation throughout the project and the objectivity is therefore good.

4 Theoretical Frame of Reference

This section presents the relevant theoretical background required for a thorough understanding of this thesis. First, some general terms will be briefly introduced. This will be followed by a description of statistical distributions and optimization of reorder points, both for an uncoordinated and a coordinated system. The relation between service level and shortage costs will also be included.

4.1 General definitions

Holding cost	The cost of keeping one product in stock for one time unit.
Shortage cost	The cost per unit and time unit of not having a product in stock when it is demanded.
Lead time	The time it takes to receive an order after placing it, including the potential delays due to stock out at upper echelons.
Transportation time	The time it takes to receive an order after placing it, given that it can be delivered immediately (may include fixed times for picking, receiving and other handling).
Lost sales	When customers leave the store empty handed because the demanded item is not available. This presumes that the customers are not willing to wait until the product is delivered from the next level supplier.
Backorder	Occurs when a customer waits for an order until it becomes available, if the supplier is out of stock at the time the order is placed. This can lead to a queue.
Inventory level	The actual physical inventory on hand
Inventory position	The inventory level plus outstanding orders minus possible backorders.
$SERV_1$	Probability of no stockout per order cycle, also known as cycle service level.

$SERV_2$ Fraction of demand that can be satisfied immediately from stock on hand, also referred to as the fill rate.

$SERV_3$ Fraction of time with positive stock on hand, also known as ready rate. $SERV_3$ =$SERV_2$ when demand is continuous or customers can only purchase one unit a time.

(R,Q)-policy Stock replenishment policy where Q units are ordered as soon as the inventory position drops down to or below R. The maximum inventory level can thus be R + Q.

4.2 Statistical distributions

During the course of this master's thesis, a number of statistical distributions are used. This section will give a basic overview of the distributions that concern the project.

4.2.1 Normal distribution

The normal distribution with its well known bell shaped probability density function is a continuous distribution that describes a variable that tends to cluster around the mean, see Figure 4. The function is symmetrical around its mean value, and the further away from the mean, the less is the probability of the stochastic variable having that value. The standard deviation of the normal distribution (σ) measures the variability. A small standard deviation means that the values are concentrated around its mean as opposed to a large, which implies a larger variability. The normal distribution is not restricted to positive values[43].

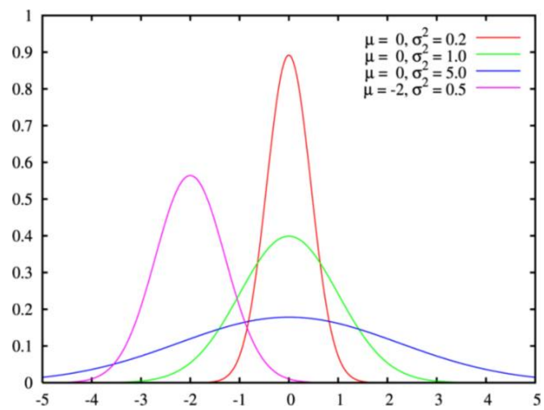

Figure 4: Examples of some normal distributions

It has been proved that a sum of independent identically distributed random variables is normally distributed as the number of variables approaches infinity. This is called the Central Limit Theorem. For this reason, and the fact that the distribution is easy to handle mathematically, the normal distribution is commonly used[44].

The density and cumulative distribution functions of the normal distribution are:[45]

Density function: $$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (4.1)$$

Cumulative distribution function: $$F(x) = \int_{-\infty}^{x} f(x)dx \quad (4.2)$$

[43] Ross. 1985. *Introduction to Probability Models* p. 35
[44] Ibid p. 71
[45] Vännman. 2002. *Matematisk statistik* p. 155

4.2.2 Exponential distribution

The exponential distribution is a distribution suitable to approximate times between arrivals to a queuing system, as empirical studies have shown that this is often the case. Furthermore the exponential distribution has qualities which make it mathematically easy to handle.[46] The distribution has the following density and distribution function:[47]

Density function: $$f(x) = \lambda e^{-\lambda x} \tag{4.3}$$

Cumulative distribution function: $$F(x, \lambda) = \begin{cases} 1 - e^{-\lambda x}, & x \geq 0 \\ 0, & x < 0 \end{cases} \tag{4.4}$$

where λ is the mean number of occurrences per time unit.

The main advantage with the exponential distribution is that it is memoryless. This means that, at any given time, the expected time until the arrival of the next customer will be 1/λ, regardless of when the previous arrivals occurred. This property makes the exponential distribution unique.[48] The independency makes the distribution suitable for representing times between end customer arrivals.

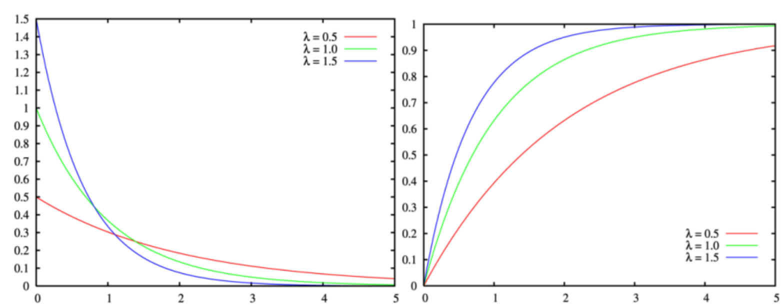

Figure 5: Density and cumulative distribution functions for some exponential distributions

[46] Laguna & Marklund. *Business Process Modeling, Simulation, and Design.* 2005, p. 182
[47] Vännman. 2002. *Matematisk statistik,* p. 113
[48] Körner. 2003. *Köteori,* p. 316.

4.2.3 Poisson process

When times between customer arrivals are exponentially distributed and each customer only demands one unit the demand is said to follow a Poisson process.[49]

In the special case when the variance is equal to the mean demand, and the exact demand distribution is not known, the customer behavior is often approximated with a Poisson process. The expected time between arrivals will be $1/\lambda$. The Poisson process is therefore suitable to use when the variance (σ^2) divided by the mean (μ) is between 0.9 and 1.1. In cases when σ^2/μ < 0.9 it is common to estimate the customer behavior as a Poisson process, even though this will lead to an overestimation of the variance[50].

4.2.4 Compound Poisson process

The Compound Poisson process enables customers to purchase more than one unit, which in many real cases better captures reality. The times between customer arrivals are still exponentially distributed, but the amount of units each customer orders is assumed independent of other customers' orders and follow a discrete distribution, called the compounding distribution. [51]

For unknown demand patterns, when the variance of the demand is relatively larger than the mean (σ^2/μ > 1.1), a compound Poisson process may be suitable to represent the customer behavior.[52]

[49] Law & Kelton. 2000. *Simulation modeling and analysis*, p. 326
[50] Axsäter. 2006. *Inventory Control,* p. 85
[51] Ibid*,* p. 78
[52] Ibid*,* p. 78

4.2.5 Gamma distribution

The gamma distribution has two input parameters, a scale parameter (β) and a shape parameter (α). The sum of gamma distributions with the same scale parameter will also follow a gamma distribution. The density and distribution functions of the gamma distribution are:[53]

Density function: $f(x) = x^{\alpha-1} \frac{e^{-x/\beta}}{\beta^{\alpha}\Gamma(\alpha)}$, for $x > 0$ and $\alpha, \beta > 0$ (4.5)

Cumulative distribution function: $F(x) = 1 - e^{-x/\beta} \sum_{j=0}^{\alpha-1} \frac{(x/\beta)^j}{j!}$, $x > 0$ (4.6)

In the case of α = 1, the gamma distribution is equal to an exponential distribution with parameter β.

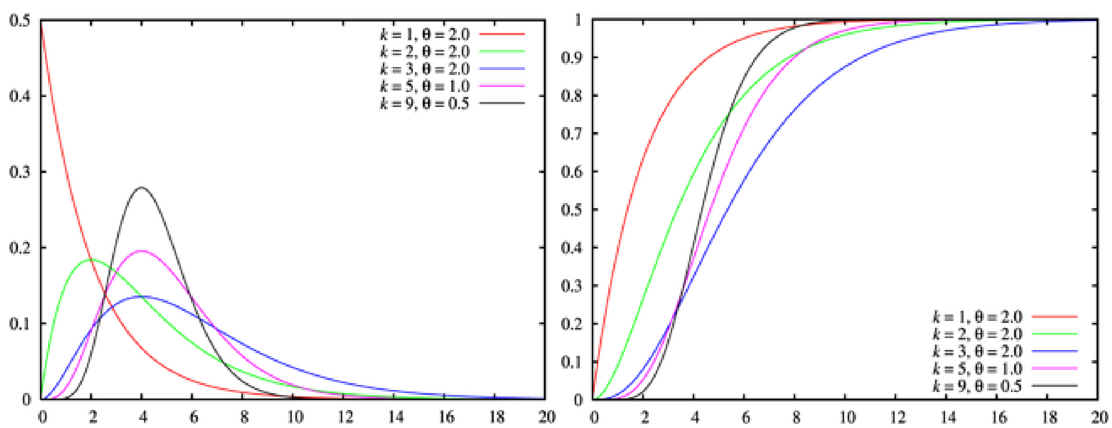

Figure 6: Cumulative distribution function for some gamma distributions

[53] Law & Kelton. 2000. *Simulation modeling and analysis*, pp.302-303

4.3 Relation between demand over time and inter arrival times

There are distributions that estimate the number of events per time units and that can be transformed into other distributions estimating the inter arrival times through mathematical formulas.

4.3.1 Compound Poisson process[54]

With the assumptions that the times between arrivals are exponentially distributed and that the demand size has a logarithmic distribution, it is possible to calculate lambda and the probability of a customer buying any number of articles. With these two assumptions, the demand distribution follows a so called Negative Binomial distribution.

A variable called alpha (α) is calculated to simplify the other calculations required.

$$\alpha = 1 - \frac{\mu}{\sigma^2} \tag{4.7}$$

The arrival intensity can be calculated with the following formula:

$$\lambda = -\mu \frac{(1-\alpha) * \ln(1-\alpha)}{\alpha} \tag{4.8}$$

The probability of each demand size can be calculated:

$$f_j = -\frac{\alpha^j}{\ln(1-\alpha) * j} \tag{4.9}$$

Where j is the number of units demanded.

4.4 Single echelon systems

A single echelon inventory system consists of a single inventory installation[55]. Literature on the subject is today widely available and there are many different methods for analyzing and optimizing this type of system under various conditions and assumptions. What method to choose depends on the assumptions that are made. Some of the assumptions that affect the choice of method are:

[54] Axsäter. 2006. *Inventory Control,* pp. 80-81
[55] Axsäter. 1991. *Lagerstyrning,* p. 38

- Whether the distribution is discrete or continuous
- If the lead time is stochastic or constant
- What order policy is used
- Whether a continuous or periodic review policy is being followed
- If lost sales or backorders occur
- What definition of service level is used to control the inventory
- Cost optimization with back order penalty cost or other service level constraints

Assuming a normally distributed demand, a constant lead time, fixed order quantities, continuous review and a backorder system, $\mathrm{f(x)}$ and $\mathrm{F(x)}$ is the density and distribution function of the distribution of the inventory level. μ' is the mean and σ' the standard deviation of the lead time demand. The normal distribution has the density function $\varphi(\mathrm{x})$ and the distribution function $\phi(\cdot)$. Given these conditions, the distribution function of the inventory level can be expressed as[56]:

$$F(x) = P(IL \leq x) = \frac{1}{Q} * \int_R^{R+Q} \left[1 - \Phi\left(\frac{u-x-\mu'}{\sigma'}\right)\right] du \qquad (4.10)$$

If the *loss function* G(x) is introduced, as

$$G(x) = \int_x^{\infty} (v-x)\varphi(v)dv = \varphi(x) - x(1-\Phi(x)) \qquad (4.11)$$

then G'(x) is:

$$G^{'}(x) = \Phi(x) - 1 \qquad (4.12)$$

[56] Axsäter. 2006. *Inventory Control,* pp. 85-91

Using the loss function, F(x) can be reformulated as[57]:

$$F(x) = \frac{1}{Q} * \int_{R}^{R+Q} \left[-G'\left(\frac{u-x-\mu'}{\sigma'}\right)\right] du = \frac{\sigma'}{Q} * \left[G\left(\frac{R-x-\mu'}{\sigma'}\right) - G\left(\frac{R+Q-x-\mu'}{\sigma'}\right)\right] \quad (4.13)$$

As stated in Section 4.1, $SERV_3$ is the fraction of time with positive stock. Under the assumption of continuous demand, $SERV_2$ equals $SERV_3$, and the service level can be expressed as[58]:

$$SERV_2 = SERV_3 = 1 - F(0) = 1 - \frac{\sigma'}{Q}\left[G\left(\frac{R-\mu'}{\sigma'}\right) - G\left(\frac{R+Q-\mu'}{\sigma'}\right)\right] \quad (4.14)$$

From this formula, it is then easy to find the lowest possible reorder point satisfying a given service level requirement by increasing R until the service level is reached.

From the formula above also follows the relation between service level and shortage cost. This can be useful when trying to compare two different inventory control systems. For example it is difficult to determine which system is best, the one with higher inventory levels and a better service, or the one with low inventory levels and lower service. Transforming the service level into a shortage cost makes it possible to compare the systems by quantifying total holding and shortage cost. The formula used for transforming the service level ($SERV_2$) into the shortage cost (p), given the holding cost (*h*), is[59]:

$$p = \frac{h * SERV_2}{1 - SERV_2} \quad (4.15)$$

This means that if p according to 4.15 is used when minimizing the expected total inventory holding and shortage cost it will render a solution R with a service level $SERV_2$.

[57] Axsäter. 2006. *Inventory Control,* p. 92
[58] Ibid, p. 98
[59] Axsäter. 1991. *Lagerstyrning,* p. 75

4.5 Multi echelon inventory system[60]

In practice, multi echelon inventory systems, where a number of installations are coupled to each other, are very common. The interest for taking the connections between different levels of inventory into account when optimizing inventory control has grown in the past two decades. This is partly due to the increased possibilities because of the research now available as well as the improved information and communication technologies.

A *distribution system* is often constructed as in Figure 7, with one distribution center that delivers to a number of retail stores. In a pure distribution system, each stock has at most one single predecessor. The inventory level at the distribution center will determine the lead time to the retail stores and therefore influence the service level that the retail stores can offer the end customers. The higher the inventory at the distribution center, the lower inventories need to be kept at retail stores. On the other hand, the holding costs at the distribution center will increase. The optimal inventory levels for the total stock system will depend on the structure, the demand variations, the transportations times, the unit costs and the replenishment and allocation policies.

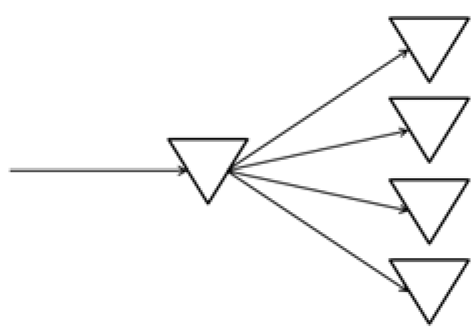

Figure 7: Distribution system

[60] Axsäter. 2006. *Inventory Control,* pp. 188-191

Figure 8 shows an assembly system common in manufacturing situations. Inventories with raw material are delivered to installations where they are processed or sub assembled and at the end of the chain, the final product is stored. It is typical for this kind of system that the early inventories contain items with much lower value than in the end. A *convergent flow* has at the most one immediate successor.

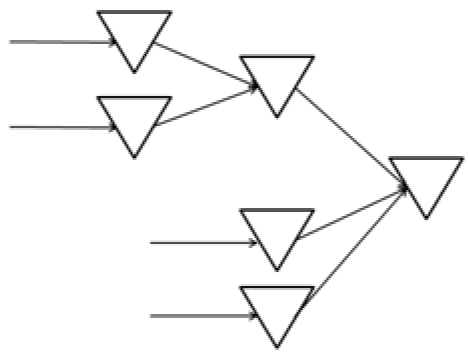

Figure 8: Inventory system with convergent flow

It is, of course, both possible and common to have a mixture between divergent and convergent systems. An example of a *general* multi echelon *inventory system* is found in Figure 9.

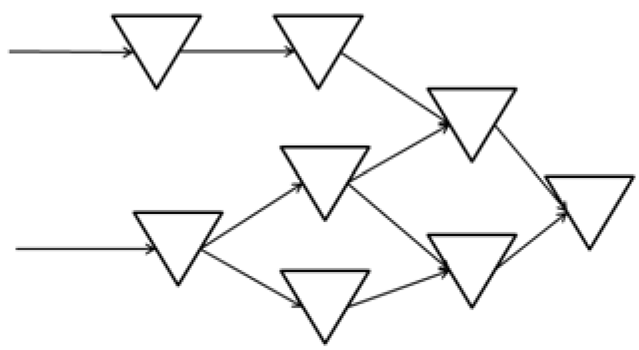

Figure 9: General multi echelon inventory system

4.6 A method for optimization of multi echelon inventory systems

This section will give an intuitive understanding of the theory behind the model developed at the division of Production Management at Lund University. This model is used in this project to estimate reorder points for a multi echelon system. The model itself will be further discussed in Section 5.2.5. The theory discussed below is based on three scientific articles. The first article studies an optimization method for a multi echelon system with identical retail stores[61]. In the second article the problem is solved for non-identical retail stores[62]. Finally, in the last article, it is investigated how an induced backorder cost at the distribution center could be estimated, making the calculations less numerically demanding[63].

4.6.1 Coordinated decentralized multi echelon inventory control

Following the articles mentioned above, the following notations are used in the description of the model[64]:

N	number of retail stores
Q	largest common divisor of all order quantities in the system
q_i	order quantity at retail store i, expressed in units of Q
Q_i	order quantity at retail store i, expressed in number of units
Q_0	distribution center order quantity, expressed in units of Q
h_i	holding cost per unit and time unit at retail store i
h_0	holding cost per unit and time unit at distribution center
p_i	shortage cost per unit and time unit at retail store i
L_0	constant lead time for an order to arrive at the distribution center
l_i	constant transportation time between the distribution center and retail store i
L_i	lead time for an order to arrive at retail store I, stochastic variable
$\bar{L}_i$	expected lead time for an order to arrive at retail store i
μ_i	expected demand per time unit at retail store i

[61] Andersson et al. 1998
[62] Andersson & Marklund. 2000
[63] Berling & Marklund. 2006
[64] Ibid

μ_0 expected demand per time unit at distribution center

σ_i standard deviation of the demand per time unit at retail store i

$D_0(t)$ retail store demand at the distribution center during the time period t, expressed in units, stochastic variable

R_i reorder point for retail store i

R_0 reorder point for the distribution center in units of Q

C_i expected cost per time unit at retail store i

C_0 expected cost per time unit at the distribution center

TC expected total system cost per time unit

$B^i_0(R_0)$ expected number of backordered units at the distribution center designated for retail store i when the reorder points is R_0

$B_0(R_0)$ expected number of backordered units at the distribution center given R_0

Before describing the method to optimize reorder points it is important to specify the assumptions in which it rests. These are also the assumptions used during the course of this master's thesis, when applying the model to IKEA's inventory system.

The model includes a central distribution center that supplies N number of non-identical retail stores. This corresponds to a distribution inventory system, as described and seen in Section 4.5. The distribution center is replenished by outside suppliers with the assumption that the transportation time, L_0, is constant and this can be interpreted as no risk of shortages at the supplier. All retail stores and the distribution center apply continuous review installation stock (R,Q)-policies. All order quantities are assumed to be fixed and pre-determined. This constraint may seem to be restrictive, but in reality it not as damaging as it appears to be. First, box and pallet sizes often lead to only a few order quantities being feasible in practice Secondly, one can show that the choice of Q only marginally affects the results as long as the associated reorder points are optimized correctly[65]. Besides, it is easy to use the model to search over different order quantities making the restriction even smaller. At the distribution center,

[65] Zheng. 1992

the initial inventory position, the reorder points and the batch size are integer multiples of Q, which is the largest common divisor of all order quantities in the system.[66]

The lead times between the distribution center and the retail stores are assumed to be constant, where the stochastic lead time is replaced with its correct average. This approximation has been shown to work quite well, and makes the numerical calculations much less demanding[67]. At the distribution center and at the retailers, orders are delivered based on a first-come, first-serve policy, which means that the orders and demands are satisfied in the sequence they arrive. This means that an order is independent of the demand at the distribution center after its placement. The inventory position at the distribution center is always non-negative, $R_0 \geq -Q$, and the maximum delay at the distribution center is thus the lead time L_0. The model assumes that only complete deliveries are sent to retail stores. Regarding transportation and other fixed costs associated with delivery, a policy of complete deliveries is often applied in reality.[68]

With these assumptions made, the theoretical model will now be discussed.

The purpose of the model is to jointly optimize the reorder points in the system. One might also consider searching over alternative order quantities to find the best alternative, but this is not investigated in this approach. The objective is to minimize the system's total costs, that is, the sum of expected costs and shortage costs. The expected total cost can thus be expressed as:[69]

$$TC = C_0 + \sum_{i=1}^{N} C_i \tag{4.16}$$

The solution approach is based on decomposing the multi echelon inventory problem into N+1 (N retail stores + distribution center) single echelon problems which are relatively easy to solve by the same logic as an uncoordinated system.

[66] Andersson & Marklund. 2000
[67] Andersson et al. 1998
[68] Ibid
[69] Ibid

The demand at the distribution center is determined based on the demand at all retail stores D_i and the order quantities Q_i. A target fill rate is not set at the distribution center. To connect the distribution center problem to the retail stores an induced backorder cost (β) is introduced to the total cost of the distribution center. The induced backorder cost can be seen as a penalty cost for the distribution center in case of shortages at the retail stores[70].

The exact method of calculating the induced backorder cost for each retail store is an iterative process, which is computationally demanding. After studies on how the different parameters affect the induced backorder costs, the following equation has been developed for estimating β*. It has been shown to give very similar results as the exact method and can therefore be used as an approximation when optimizing reorder points for multi level inventories:[71]

$$\beta_i^*\left(\sigma_{i,}Q_i, p_i\right) = g(Q_i, p_i) * \sigma_i^{k(Q_i, p_i)} \tag{4.17}$$

After the induced backorder costs are calculated for each retail store, a weighted average for the distribution center can be determined by: [72]

$$\beta^* = \sum_{i=1}^{N} \frac{\mu_i}{\mu_0} \beta_i^* \tag{4.18}$$

With the backorder cost set, it is relatively easy to optimize the reorder point at the distribution center, R_0, by minimizing:[73]

$$\tilde{C}_0(R_0) = C_0(R_0) + \beta^* * \frac{1}{Q} * \sum_{R_0+1}^{R_0+Q_0} E_{D_0(L_0)}[(D_0(L_0) - y_0 * Q_0)^+] \tag{4.19}$$

[70] Andersson et al. 1998
[71] Berling & Marklund. 2006
[72] Ibid
[73] Andersson & Marklund. 2000

Where the holding cost at the distribution center is the sum of the cost of inventory on hand and the holding cost for reserved units. :

$$C_0(R_0) = h_0 * E[IL_0^+] + h_0 * Q * E[B_0^r] \qquad (4.20)$$

In which the expected mean inventory on hand ($E[IL_0^+]$) can be expressed as:

$$E[IL_0^+] = \frac{1}{Q_0}\sum_{y_0=R_0+1}^{R_0+Q_0} E_{D_0(L_0)}[(y_0 Q - D_0(L_0))^+] \qquad (4.21)$$

The R_0 above is then used to get the expected mean lead time for each retail store[74]:

$$\bar{L}_i(R_0^*) = \frac{E[B_0]*Q}{\mu_0}\left(1 + \frac{\mu_i*(Q_i-Q)-\left({}^{\eta_i}/_N\right)}{\eta_i}\right) + \frac{E[B_0^r]*Q}{\mu_0} * \frac{\mu_i*(Q_i-Q)}{\eta_i} + l_i \qquad (4.22)$$

Where

$$\eta_i = \sum_{i=1}^{N} \mu_i(Q_i - Q) \qquad (4.23)$$

And

$$E[B_0^r] = E\left[\left\lceil\frac{B_0}{\bar{Q}}\right\rceil \bar{Q}\right] - E[B_0] \qquad (4.24)$$

Where

$$\bar{Q} = \sum_{i=1}^{n} \frac{\mu_i}{\lambda_0} \qquad (4.25)$$

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[74] Berling & Marklund. 2006

In which

$$\lambda_0 = \sum_{i=1}^{n} \frac{\mu_i}{Q_i} \tag{4.26}$$

With the given lead times each retail store problem can be solved individually. The general cost per time unit formula for each retail store i is:[75]

$$C_i(R_0, R_i) = h_i * E(IL_i^+) + p_i * E(IL_i^-) = h_i * E(IL_i) + (h_i + p_i) * E(IL_i^-)$$
(4.27)

For the case of normally distributed demand, the retail store costs can be expressed as:[76]

$$C_i\left(R_i \middle| \bar{L}_i(R_0)\right) = h_i\left(\frac{Q_i}{2} + R_i - \mu_i \bar{L}_i\right) + (h_i + p_i) * \frac{\sigma_i^2 * \bar{L}_i}{2Q_i}\left[H\left(\frac{R_i - \mu_i \bar{L}_i}{\sigma_i \bar{L}_i^{1/2}}\right) - \right.$$

$$HRi-\mu iLi+Qi\sigma iLi12$$

(4.28)

where:

$$H(v) = (v^2 + 1)\left(1 - \phi(v)\right) - v\varphi(v) \tag{4.29}$$

In this case, $\phi(\cdot)$ is the standard normal distribution and $\varphi(\cdot)$ is the normal density function.

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[75] Axsäter. 2006. *Inventory Control,* p. 101
[76] Andersson et al. 1998

By minimizing the cost for each retail store in the formula above, the optimal reorder points are determined. This concludes the method used in the analytical model. To summarize the method, a short list of the steps is presented below.

1. Determine the demand distribution at the distribution centers (D_0)
2. Determine the induced backorder cost for each retail store and then for the distribution center
3. Determine the demand distribution at the distribution center
4. Determine the optimal reorder point at the distribution center
5. Calculate the average lead time for the retail stores
6. Determine the optimal reorder point for each retail store

5 Determination of reorder points

This chapter will clarify how the reorder points are determined for a sample of articles at IKEA. This includes a discussion of the data provided and how it was processed as well as a presentation of the model that was used to calculate reorder points. The chapter also includes the assumptions made in the master's thesis and, at the end, the method currently used to determine safety stock at IKEA.

5.1 Input data

The determination of reorder points is done by the analytical model described in Section 4.6.1. The model is implemented in Microsoft Excel. The input parameters required by the model are:

- Average customer demand per time unit
- Standard deviation for the customer demand
- Order quantities for the distribution centre and retail stores
- Lead time for the distribution center and transportation times for the retail stores
- Relation between the holding and shortage cost, or target fill rate.
- The relation between the holding cost at the distribution center and at the retail stores

The data provided by IKEA is:

- Weekly sales for one year (from week 12 in 2008 to week 11 in 2009)
- Orders placed by retail stores to the distribution center during the same weeks as above
- Orders placed during six months by the distribution centers (from week 2 to week 35 in 2009)
- Service level targets for all articles
- Lead times from suppliers to distribution centers
- Lead times from distribution centers to retail stores for all articles

The time unit chosen for the project is one week due to the fact that the sales data available is compiled weekly. The demand, standard deviation and order quantities had to be calculated or estimated. The procedure of doing this is described in the next section. The other input parameters required no further processing.

Initially, data for approximately 250 articles was provided. Due to incomplete data for some of the articles, reorder points could only be calculated for 114 of them. An example of the compiled data for one article can be found in Appendix 7.

5.2 Processing of data

5.2.1 Sorting data

The first step in the procedure of processing data was to sort the sales data according to article number and then store number.

Articles where sales data was available for less than 50% of 52 weeks for the 17 stores were removed and no longer studied. These articles are not considered representative for high flow products.

Articles that have been introduced during the investigated year have been disregarded. Since the articles were new, the weekly sales have probably not yet stabilized enough to draw valid conclusions. Following the same logic, articles that have been removed from the range of products during the year have been excluded from the study.

In February 2009, a new IKEA store was opened. The store belongs to the distribution centre group studied in this report, but has been disregarded due to the small amount of sales data that was available at the time.

5.2.2 Mean demand per time unit, μ, and standard deviation, σ

The mean demand per week, for each article and store, was calculated by taking the mean value of the weekly sales for the last 52 weeks that was provided by IKEA. The standard deviation was estimated for the same data, using the sample standard deviation estimation:

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

For the cases where there were 52 values this was a straightforward procedure. However, many of the provided articles had less than 52 recorded values in the given data. The explanation is either that the demand was zero, or that the store was out of stock that particular week. In the case of lack of demand, the zero value affects both mean value and standard deviation. That is not necessarily the case with the out of stock situation. This becomes a problem because the demand is not the same as sales. There is a possibility of the customer coming back in the future and purchasing the product, in which case the demand is registered. But there will also be situations of lost sales, which if seen as no demand, that will give a misleading picture of the mean value and standard deviation.

For weeks with zero sales, there is unfortunately no way of telling from the provided data if there is no demand or if the store had no articles available at the time. Also, in the case of no stock, there is no way of saying if the customer comes back later or is lost. In other words, zero sales are assumed to be equal to zero demand. When calculating the mean weekly demand and standard deviation, zeros are therefore added to the data, so the calculation is always made for 52 values.

There are cases with negative sales data which have been set to zero. The reason is that the negative values are few and minimum values are -2, therefore handling them further would give unnecessary work load and does not add much value to the results. Furthermore, negative values are assumed to be returned items, and these are most often not put out for sale again, affecting the results even less[77].

5.2.2.1 Correlation of demand

The normal approximation in the analytical model used assumes that there is no correlation in the demand. The authors of this paper refer to the previous study that shows that this is true.[78] Furthermore, it is obvious that the typical IKEA end customers arrive independently to the retail store.

5.2.3 Batch size Q and number of batches q_i

In order to use the model described in Section 5.2.5, the order quantities at each installation, both at retail stores and at the distribution centers, need to be constant. For most of the articles however, this is not the case. For the order quantities at the retail stores there are three different cases of ordered quantities during the time investigated. The three cases are illustrated with examples in Table 1. Three articles have been picked to explain each case. Each example represents 5 different orders from one single retail store and the two bottom lines show the chosen batch size and amount of batches ordered.

- *Case 1*: Order quantities from all stores are multiples of a common number, Q. The number of batches in all orders for one store is always the same, q_i. Batch size is set to the multiple, Q, and the amount of batches to q_i, see Article 1 in Table 1.

[77] Björnsson. 2009. Älmhult
[78] Dahlberg et. al. 2009

- *Case 2:* Articles where the quantities from all stores are multiples of a certain number, Q. However, each store orders different multiples of Q at different times of ordering. The input to the model in this case is assumed to be the lowest observed quantity. An explanation of this phenomenon is that when the inventory level drops below R-n*Q between inspections in a period review system, then n+1 batches will be ordered. Batch size is set to the multiple, Q, and the amount of batches to the minimum q_i, see Article 2 in Table 1.
- *Case 3:* There are articles where the order quantities are not multiples of any common number. The input q_i used in the model for these articles is the lowest quantity ordered, and the multiple Q is set to be 1, see Article 3 in Table 1.

Table 1: Determination of order quantities

Store X	Article 1	Article 2	Article 3
Ordered quantity 1	24	12	6
Ordered quantity 2	24	8	2
Ordered quantity 3	24	12	7
Ordered quantity 4	24	8	2
Ordered quantity 5	24	4	2
Batch size, Q	24	4	1
Amount of batches, qi	1	1	2

5.2.4 Holding and shortage costs

When calculating the reorder points of an inventory system, it is not necessary to know the exact holding cost and shortage cost. What is important is the relation between the two. When using the analytical model, the holding cost was set to one monetary unit per time unit and product, and the relative shortage cost was then calculated by using equation 4.15 in Section 4.4 to satisfy the target service level.

5.2.5 The analytical model

For determining the reorder points for a multi level inventory system, the analytical model described in Section 4.6.1 was used. The model is developed by researchers at the Division of Production Management at Lund University, Faculty of Engineering. The model is programmed in Microsoft Excel, using Macros in Visual Basic for the more advanced calculations. A picture of the interface is found in Appendix 1.

The model is based on the assumption that the customer demand during the lead time follows a normal distribution. If this condition is violated the normal distribution is an approximation. The simulation model, which is not restricted to a normal demand assumption (see Section 6.2.1) will partly answer this.

5.2.5.1 Additional settings

Apart from entering the input parameters to the model, there are two additional choices needed to be made before running it, as seen in Appendix 1: CW_demand and Choice.

CW_demand sets the statistical distribution for the demand at the warehouse. There are three possible alternatives. Choice number 1 calculates the exact demand, given the normal demand assumption of customer demand. This is obviously to prefer, but it may be computationally demanding and take an unreasonable amount of time if the order quantities q_i and Q_i are very different. The second best alternative is to approximate the demand to the warehouse with a gamma distribution (choice number 3). This is a better approximation than the normal distribution as the gamma distribution cannot have negative values.

Problems with this approximation can however occur if the mean demand is significantly larger than the standard deviation. In some of these cases, the computer is unable to proceed with the calculations due to weaknesses in Excel. The third and last alternative is to assume a normal distribution for the demand. The main problem with this is that with the normal distribution including negative realizations, which are not allowed. The model is not able to consider returned items. The problem decreases as the mean value is relatively large compared to the standard deviation, which means that the probability for negative demand decreases. In order to ensure that this does not happen, the model is built with a function that sends a warning signal if the probability of negative demand is too large.[79]

[79] Marklund. 2009. Lund

A validation has been done for some articles, to ensure that the three alternatives do not differ from each other too much. Three runs were made for each article, with the CW_demand as the only changed parameter. Table 2 gives the calculated reorder points for two examples of the test for the exact distribution, and the difference from these for the normal and gamma approximation.

Table 2: Comparison of different CW_demand choices. Exact method subtracted from normal and gamma

	CW_demand		
	1 Exact	2 Normal	3 Gamma
DC	32,0000	0,0000	0,0000
STO1	6,6110	-0,0008	-0,0097
STO2	8,6349	-0,0010	-0,0166
STO3	10,4774	-0,0014	-0,0213
STO4	5,2265	-0,0006	-0,0104
STO5	5,1549	-0,0006	-0,0110
STO6	9,6456	-0,0015	-0,0203
STO7	3,7116	-0,0006	-0,0075
STO8	6,2459	-0,0009	-0,0128
STO9	9,8057	-0,0014	-0,0186
STO10	8,2612	-0,0010	-0,0167
STO11	6,9545	-0,0009	-0,0146
STO12	8,5078	-0,0011	-0,0175
STO13	6,6488	-0,0009	-0,0141
STO14	3,8420	-0,0005	-0,0078
STO15	4,0874	-0,0005	-0,0086
STO16	5,2134	-0,0006	-0,0107
STO17	6,0397	-0,0009	-0,0121

	CW_demand		
	1 Exact	2 Normal	3 Gamma
DC	6,0000	0,0000	0,0000
STO1	10,0712	0,0226	-0,1195
STO2	4,0594	0,0121	-0,0649
STO3	4,1054	0,0123	-0,0650
STO4	7,3219	0,0193	-0,1018
STO5	1,6204	0,0068	-0,0353
STO6	3,4617	0,0108	-0,0572
STO7	1,8300	0,0071	-0,0379
STO8	3,0343	0,0100	-0,0524
STO9	1,6770	0,0070	-0,0360
STO10	0,8444	0,0050	-0,0256
STO11	3,1280	0,0102	-0,0535
STO12	4,9641	0,0142	-0,0748
STO13	4,7603	0,0136	-0,0724
STO14	2,3023	0,0081	-0,0435
STO15	2,1992	0,0080	-0,0423
STO16	1,7615	0,0071	-0,0369
STO17	1,2827	0,0060	-0,0311

As seen in the table above, the differences in reorder points are negligible and the three alternatives can therefore be used without risking the validity. It is worth mentioning that the reorder points will be rounded to the nearest integer and the differences will therefore most likely have no influence what so ever.

The “Choice” option controls how the induced backorder cost at the warehouse (β) is set, see Section 4.6.1. This can be done either with an equation or by using table values.

5.2.5.2 Choices made

When running the model in order to calculate the reorder point for this master thesis, the equation choice has been used for all the articles. This choice has been made to ensure that all articles are treated the in the same way.

For the CW_demand choice the exact option has always been tested first. If the computer had difficulties making the calculation reasonably fast, the process was aborted and the gamma choice was made. If this choice did not go through, the normal distribution was used as an approximation. The allocation of the tested articles was around one third for alternative 1, 2 and 3 respectively.

5.3 Current reorder points

To be able to compare the reorder points from the coordinated approach with the current system, the current reorder points need to be estimated. Today, IKEA places new orders when the inventory levels are lower than the forecasted demand during the so called safety days. The safety days for a store and article are the amount of days that the local inventory should be able to supply according to forecasted demand, without refills. The safety days as well as the forecasted demand are constantly updated. Some articles, in addition to safety days, also have a minimum and maximum limit for the safety stock.[80]

The safety days have not been calculated in this project due to lack of input data for the formulas and because the safety days used by IKEA were available for nearly all articles. The calculation therefore seemed unnecessary. The formulas used at IKEA are available in Appendix 10. The reorder points for the simulation of the current system are the safety days (from data) multiplied with the mean demand (which were estimated as in section 0). The mean demand to the distribution center is the sum of the mean demand to the stores.

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[80] Elmqvist. 2009. Ämhult

The safety days times the mean demand were then compared to the minimum respectively maximum safety stock levels, in the cases these existed. The limits were used when restricting the calculated value. Some articles have been removed from the range of articles that goes through the distribution center inventory during the project, and thus no information on safety days could be found. These nineteen articles have been excluded from further studies, leaving 95 articles for simulation.

The calculated safety days is suggested by the system. This is then manually overseen and the reorder points can be altered if needed.[81]

5.4 Current service level measure

5.4.1 Service level used for control

When the ERP-system used by IKEA calculates the reorder points for each store and distribution center the target service level is required as an input. By definition, this service level should be $SERV_1$.

5.4.2 Service level measured

IKEA measures the service level of their retail stores and their distribution centers once a week. For each article, the service is the fraction of the stores that have stock out of all the stores that want stock. The service level of each store is represented as the fraction of weeks with the article in stock. This service level will be denominated $SERV_{IKEA}$ from here on. $SERV_{IKEA}$ is an approximation of the theoretical definition of $SERV_3$, which is the fraction of time with positive stock.

[81] Björnsson. 2009. Älmhult

5.4.3 Service level used in project

The service level is an input parameter when calculating the reorder points with the analytical model. The model assumes that the service level input is $SERV_2$, which, given the model assumptions, is equal to $SERV_3$. The $SERV_{IKEA}$ is in a way an attempt to measure $SERV_3$. With the assumption that every customer can only purchase one product, the fill rate equals the ready rate, $SERV_2 = SERV_3$. The service level targets inserted into the model will thus be the service level targets that IKEA currently use, without transformation.

6 Simulation

This chapter will give a short description of how the simulation model is built as well as the assumptions made.

6.1 Assumptions made in the simulation

When building a model simulating reality, certain assumptions and simplifications are most likely needed to be made. During the construction of the Extend model used in this project, the following was assumed:

- A demand that cannot be immediately fulfilled at a retail store due to stock out, leaves the system and is recorded as a lost sale, despite the fact that in reality the customer might come back at a later point in time.
- The customer demand is assumed to be following a Compound Poisson distribution. This is further explained in section 6.2.1 below.
- The inventory follows a continuous review policy. That is, orders are placed directly when the inventory position drops to the reorder point.
- The transportation times from distribution center to the retail stores are constant. This means that the only variations in lead time are in cases of stock outs at the distribution center.
- The supplier of the products never runs out of stock. This means that the lead time from supplier to distribution center will be constant and equal to transportation time.
- If a retail store places an order that cannot be fulfilled immediately by the distribution center, the order is kept as a backorder and fulfilled when the products become available.
- The distribution center never delivers partial orders to retail stores. Instead, it always waits for the entire order to be available before shipping the goods.
- The order quantities at all levels are constant.

6.2 Input parameters

The parameters needed to run the model are:

- Transportation times between supplier and distribution center
- Transportation times between distribution center and retail stores
- Order quantities used by distribution centre and the different retail stores
- Starting inventory, which is the reorder points added to the order quantity (R + Q)
- Inter arrival times between customer arrivals
- Parameter for the logarithmic distribution of demanded quantity

The input parameters need to be updated when running different articles, and in order to make this process easier the Extend model has been connected to an Excel-sheet, into which the relevant data is copied.

6.2.1 Demand distribution

In Extend, customer arrivals cannot be generated by simply entering the mean and standard deviation of the demand over time. Instead, the statistical distribution of the time between customer arrivals needs to be inserted. Also, in order to ensure that the mean and standard deviation of the demand over time are correct, the number of items one customer buys is not fixed.

The relation between variation and mean value of the weekly demand is over 1.1 for the vast majority of the articles and stores. According to the theory discussed earlier, this makes the Compound Poisson distribution suitable to estimate the customer pattern. In the case of a variance mean relation of lower than 1.1, a regular Poisson distribution is used.

The reasoning above is based on the assumption that the arrivals of customers, and the number of products each customer wishes to purchase, are independent of each other. Based on the fact that the customers are end consumers of the products, this is a reasonable assumption.

The compounding distribution chosen to use is the logarithmic distribution since it is a discrete distribution with available formulas for calculating the parameters needed given mean and variance of the demand.

6.3 Output parameters of the simulation

The simulation model is built to store three types of data: mean inventory levels, $SERV_2$ and $SERV_{IKEA}$. The measurements chosen are enough to estimate the potential stock reductions as well as controlling that the service is kept at the right levels. The measurements will also enable a comparison of the theoretical fill rate and $SERV_{IKEA}$ of measuring service level, and with that, complete the secondary objective of the project.

The fact that the simulation model assumes that each customer can buy any number of articles will of course result in the fact that $SERV_2 \neq SERV_3$. This is however the best approximation that can be made, since there is no way of converting $SERV_3$ into $SERV_2$ when a customer can order more than one item at a time. In these cases, $SERV_2$ will generally be lower than $SERV_3$ since a customer demanding more items than available in stock will affect the fill rate but not the ready rate. It can thus be expected that $SERV_{IKEA}$, as an approximation of $SERV_3$, will have slightly higher values than $SERV_2$. How each output parameter is actually measured is explained below:

- The inventory levels are easily measured as the mean number of products in the relevant queue blocks.
- The $SERV_2$ measure for each retail store and the distribution center is calculated as the amount of demand that is successfully fulfilled, divided by the total amount of customers (fulfilled demand + lost sales).
- To calculate $SERV_{IKEA}$, whether or not a store has products in stock is controlled each week. For each retail store and the DC, $SERV_{IKEA}$ is calculated by dividing the number of weeks with positive stock with the total number of weeks.

A compilation of the output parameters for a sample article is found in Appendix 8.

6.3.1 Daily service level measurement

As a part of the secondary objective, the difference between measuring the service level daily and measuring it weekly was investigated. This problem was easily implemented in the model by simply measuring the want stock – have stock ratio once a day in addition to doing it once a week. At the end of each run, the results were collected and could be compared.

6.4 Building an Extend model

When creating the Extend model it was important to make the main design as similar to the actual high flow going through distribution centers, shown in Figure 2. The simulation is performed for one article at a time. The main design, which can be seen in Figure 10 is briefly described below (the internal layout of each block can be found in Appendix 2-5):

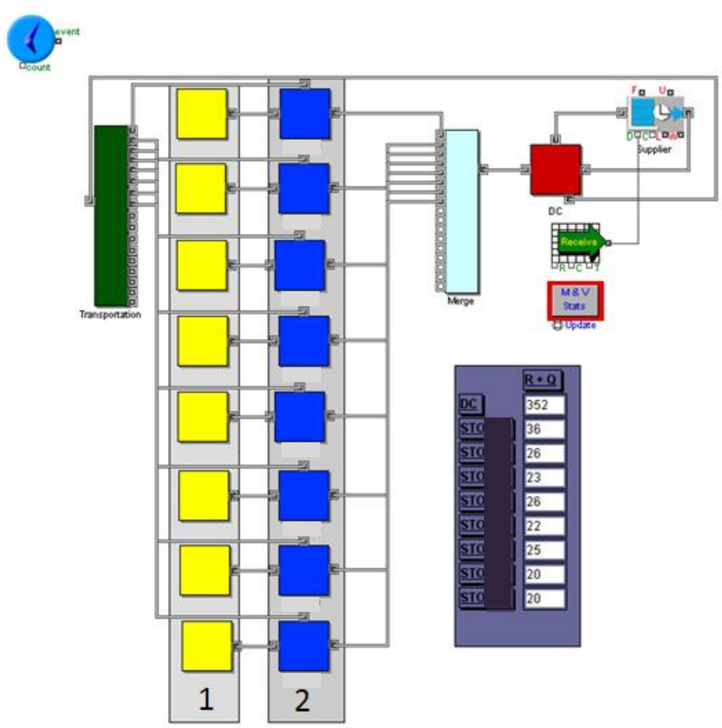


Figure 10: Main design of the Extend simulation model

- The *yellow blocks (in field 1)* generate customer demand according to a certain statistical distribution determined inside the block. It is possible for each customer to purchase more than one product.
- The *blue blocks (in field 2)* represent the retail stores. The customers are first transformed into the demand size. For example, one customer coming to purchase three items becomes three units of demand. That means that if a customer demanding more than one product arrives when there are items in stock, but not enough to fulfill the entire demand, the customer buys the products available. When the stock level reaches the reorder point, an order to the distribution center is generated. If no products are in stock at the time of a customer arrival, the customer leaves the store without the product.
- The distribution center is represented by the *red block (DC)*. This block receives orders from the stores and fulfills them with a delay to represent the lead time. When the inventory level drops below the reorder point, new items are ordered from the supplier.
- The supplier is represented by a simple delay block. When an order has been placed by the distribution center, it is delayed for the length of the lead time and then delivered.
- The *green block (Transportation)* is used to determine where the delivery should be sent. It then delivers the orders to the correct store.
- The *turquoise block (Merge)* is used to turn the seventeen different order flows into one stream, which goes into the distribution centre block.

Simulations of the inventory system have been conducted for one article at a time. Each article has been simulated twice, once with the current reorder points and once using the new calculated reorder points using the coordinated approach. In total, simulations for 95 articles were run.

6.5 Verification of the simulation model

In order to ensure that the simulation model is correct and that it gives the results it is supposed to do, the model has been compared to an existing model that is known to be correct. The comparison was done by setting all stochastic variables to constant values, and then running the two models. Since the two models give the same results, the model used in this project can be assumed to work properly as well.

6.5.1 How to ensure valid measuring

Each simulation is run thirty times, with each run going for 100 weeks. The results from each run are then used to calculate a mean for all the runs. This will decrease the risk of a certain random seed value affecting the study of a certain article.

At the start of each run every inventory is full. The reason for this is that it vastly simplifies the ordering process, by enabling the model to simply count the number of purchased products. When Q products have been sold, the inventory will be R, an order is placed. However, this will result in a skewed image of the mean inventory if the first few weeks are included, as the inventory levels will not have stabilized yet. To prevent this from happening, the Mean & Variance-blocks measuring inventory levels are reset after five weeks of running the model.

Another matter regarding the inventory levels is the fact that no partial deliveries are sent from the distribution center. This will result in some of the products that should be in stock are in fact in a Batch-block, waiting for the rest of the products filling the order. To calculate the correct inventory level in this case, it is necessary to measure both the number of items waiting to be shipped and the items in the inventory.

Finally, for the fill rate and $SERV_{IKEA}$ measurements the results will be measured at the end of each simulation run.

7 Results and analysis

This chapter summarizes the results derived from the calculations of reorder points, as well as the key performance indexes that the simulation runs have resulted in.

In the chapter, Approach 1 will be used as a name for the simulation runs with the reorder points currently used at IKEA today, and the runs using the reorder points calculated from the multi echelon model will be denoted Approach 2. The compilation of the results for the 95 studied articles is found in Appendix 6.

7.1 Service level

In order to investigate how well the two approaches performed in the sense of satisfying incoming demand, the service measured in the simulation ($SERV_2$) was compared to the target service for each of the articles. The simulation, which was done for one article at a time, measured the service for each retail store and the DC independently from each other. The service for the article was then defined as the average service for the retail stores, weighted with store's fraction of total demand. This is because a retail store with little demand should have less impact on the total service measurement for the system than one with large demand. Since the service experienced by customers is what counts, only the retail stores service levels are compared to the target.

Figure 11 shows the average system service levels obtained from the simulations with the different approaches as well as the target service level for the three different service classes. The measured service levels have been sorted from the smallest to the largest value, and dots at the same vertical do not necessarily belong to the same article. The purpose of the plot is to show how well the different approaches reach the target service level.

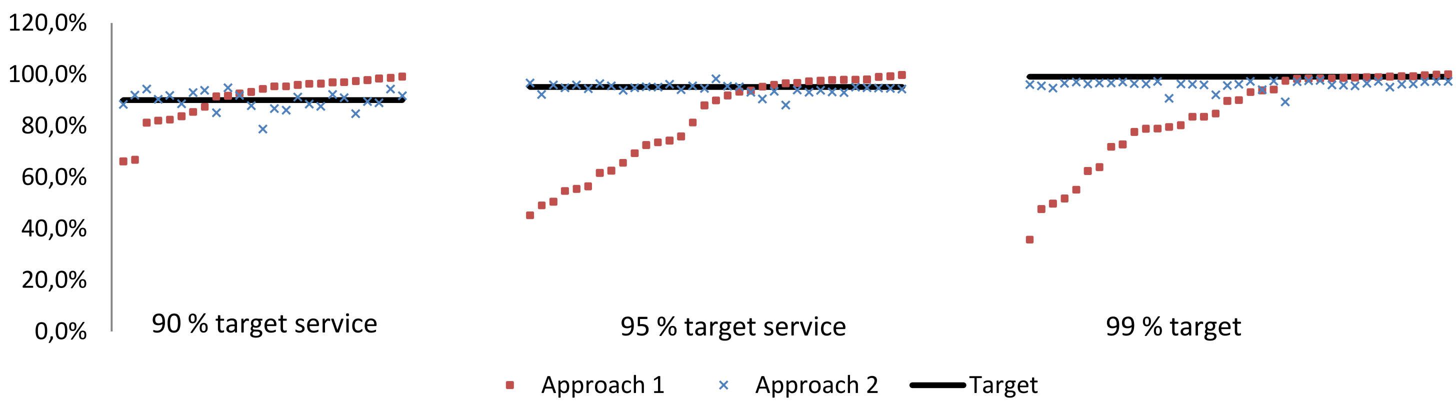


Figure 11: Target service level plotted against measured service with both approaches

From the figure above, it is apparent that the simulation for Approach 2 performs better service results than the simulation for Approach 1. Further analyses of service levels for the two approaches are performed below.

7.1.1 Service level with Approach 1

How close to the target service level the articles came when simulating Approach 1 is displayed in a pie chart in Figure 12. The chart shows the deviations in percentage points, that is:

$$(Measured\ service - Target\ service)$$

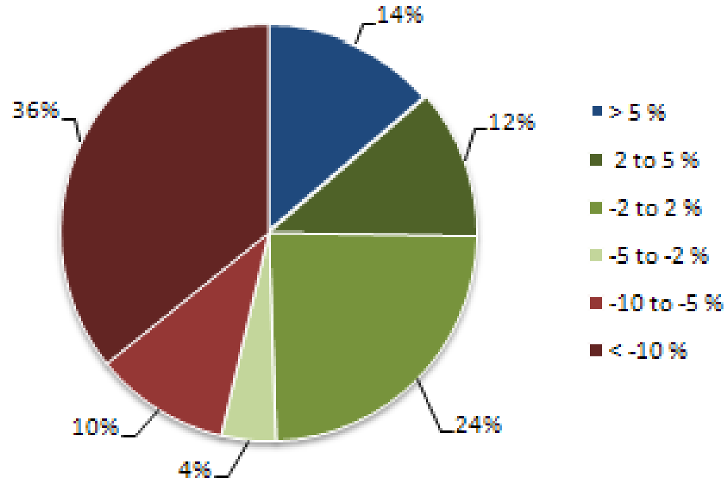


Figure 12: Deviation for the measured service from target service level, Approach 1

As the figure above shows, the service level for more than half the articles were more than five percentage points from the target service level.

7.1.1.1 Analysis of the deviation from the target service level

The recorded deviations experienced with Approach 1 may be influenced by the fact that the data for safety days and minimum safety stock were collected at different points of time than the other data used. This means that articles with drastically changed variance will have very different amounts of safety days as well.

To try to enhance the estimated current reorder points used in Approach 1, the method used to calculate the reorder points at IKEA was used. Since the historical forecast data was not available, the demand variance was approximated with the statistical variance for each article and retail store.

The calculated reorder points did not differ from the reorder points used in Approach 1 in any significant way. As this inspection did not improve the accuracy of Approach 1 neither the data nor the simulation were updated.

This problem cannot be further analyzed without data on how the reorder points are set in practice. It is known that the safety days suggested by the ERP-system are in many cases manually adjusted. This makes the real reorder points much more complicated to estimate and this might be the reason for the large deviations experienced above. Furthermore, studying the exact method with which IKEA presently sets the reorder points falls outside of the project specification.

However, IKEA’s customers do not experience that the service levels are as bad as the simulation shows. This is most likely because of the fact that the inventory is manually adjusted, up or down, by employees. If this is the case, it proves that the algorithm currently used to calculate reorder points is for many articles not appropriate.

The consequence of the large deviations from the target fill rate is that the inventory levels will be either too high or too low. In the first case, this will lead to unnecessary high service, and very large holding costs. In the second case, the inventory levels will be too low and the service will suffer. This will cause the total shortage costs to be very high.

The large variation on the results from Approach 1 makes it difficult to analyze a comparison with Approach 2. For example, articles with low service level with Approach 1 will, with Approach 2, obtain higher reorder points and thus higher inventory levels and service levels, while articles with high service level with Approach 1 will obtain lower reorder points. As the differences in service with Approach 1 are as large as they are, the results are not applicable on the entire range of articles, if only the average values are studied. For this reason the articles have been divided into three different groups depending on the system service with Approach 1 and denoted as follow:

- Group A –System service more than 5 percentage points below target service
    - Contains 44 articles
- Group B – System service within 5 percentage points of target service
    - Contains 38 articles
- Group C – System service more than 5 percentage points above target service
    - Contains 13 articles

The group that is considered as the most relevant to perform deeper comparison studies on is Group B. It is interesting to investigate how the inventory levels are affected while maintaining service.

7.1.2 Service level with Approach 2

In Figure 13 below, the average deviations in percentage points from the target service levels when simulating Approach 2 is presented.

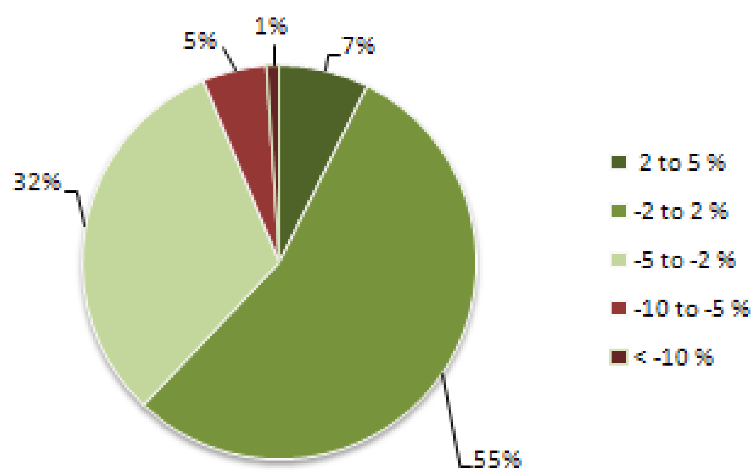


Figure 13: Deviation for the measured service from target service level, Approach 2

It is noticeable that a vast majority of the articles are close to the target service level. It can also be seen that most articles with a deviation of more than 2 percentage points have a service level lower than the targeted.

To analyze if there is any correlation between the target service level (90, 95 or 99) and how well the coordinated approach manages to reach it, the same analysis was done for each service class independently. This is illustrated in Figure 14.

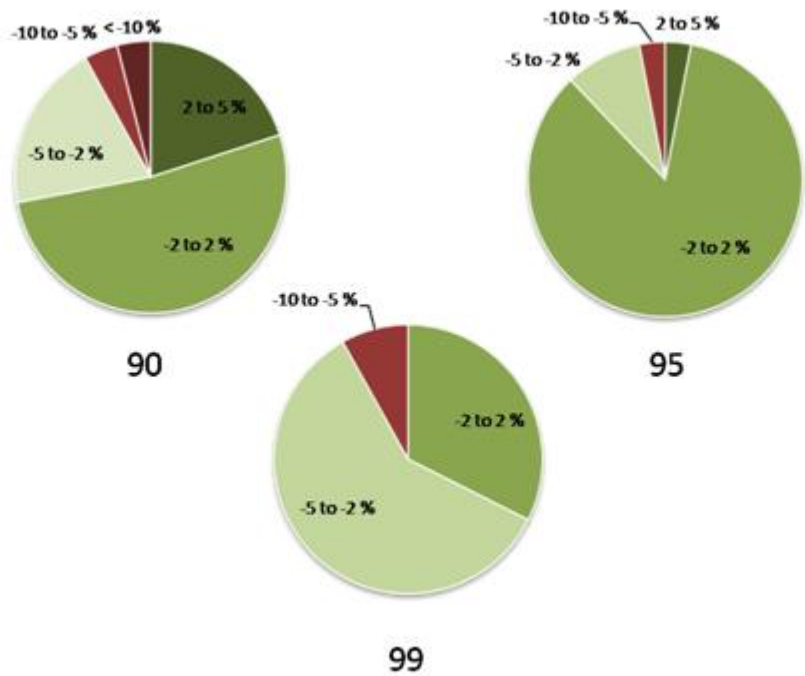


Figure 14: Service deviation, Approach 2, 90%, 95% respectively 99% articles

As seen above, the coordinated approach performed best in terms of reaching the target service for the 95% articles. Only in the 90% class cases really large negative deviation occurred. The chart for the 99% class illustrates that a large fraction of the articles did not meet the target, but landed between -2% and -5% points from the target. This clearly shows how difficult it is to achieve that few shortages, without creating overstock. The relation between inventory and service level is not linear, but rather exponential. This means that when the target service level is close to 100%, an increase in target service will require much higher inventory levels.

The reorder points are calculated with a model whose target function is attempting to exactly match the defined targeted service level. The model assumes normal distributed demand where each customer, as in all continuous distributions, can only buy one item. In the simulation model, however, each customer can demand several items. This will affect the service negatively because when the system hits the reorder point with a customer demanding more units than are available, the order is placed when the inventory position is in fact below R. This will of course increase the probability to run out of stock during the lead time, and thus increase the risk of lost sales. The reason for the few occurrences with a higher service than the target service level can be derived to the fact that reorder points are rounded up. In cases with low demand and large roundings, this can enhance the service above the target.

7.1.3 Service level at DC

As stated in the problem formulation in Chapter 2, the service level at the distribution center is not important, as long as the customers do not experience shortages. The analytical model used to determine reorder points considers this, and to investigate how this affects the service level at the distribution center, this service for both approaches is compared in Table 3.

Table 3: DC Service level

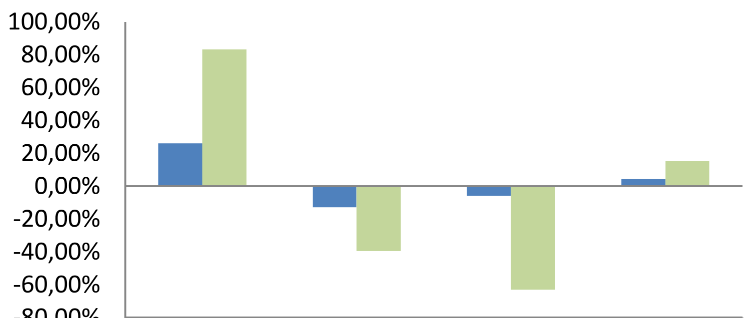
	Approach 1	Approach 2
Group A	45,7%	59,4%
Group B	82,7%	49,3%
Group C	90,3%	52,5%
All	66%	54%

As seen in the table above, Approach 2 have significantly lower service levels at the distribution center. This does not seem to affect the service level at retail level though, as Figure 12 and Figure 13 clearly shows. For Group A, the service level at the distribution center is larger with Approach 2. With this group, Approach 1 experienced difficulties reaching the target service level. This is due to too low inventories, both at DC and retail level, and both of these are expected to increase to better reach target service. The service level at DC level as well as retail level is thus expected to increase.

7.2 Reorder points

For the articles close to targeted service level (Group B), one trend could be seen. The reorder point for the distribution center was often decreased drastically, while the reorder points of the retail stores were decreased only slightly. Figure 15 below illustrates this. The bars represent the average difference, in percent, from the present reorder points, according to:

$$\sum_{i=1}^{95} \frac{(Reorder\ point\ for\ article\ i\ with\ Approach\ 1 - Reorder\ point\ for\ article\ i\ with\ Approach\ 2)}{Reorder\ point\ for\ article\ i\ with\ Approach\ 1} \Big/ 95$$

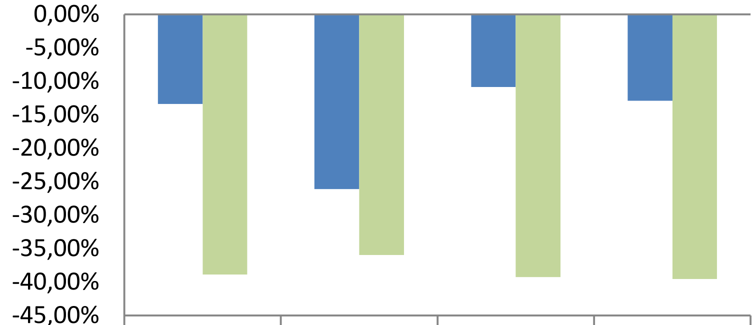


	Group A	Group B	Group C	All
Retail	25,93%	-12,95%	-5,77%	4,30%
DC	83,09%	-39,57%	-62,97%	15,30%

Figure 15: Comparison of reorder points with Approach 1 and 2

When comparing the different reorder points for the two approaches, the results were as expected. The articles for which the reorder points were larger for Approach 2 than for Approach 1 generally belongs to group A. Similarly, articles for which the reorder points for Approach 2 were smaller than for Approach 1 generally belongs to Group B and C.

For Group B, the group that is considered to be the best group for making comparisons, the changes in reorder points within the three different service classes are illustrated in Figure 16, where the bars represent the same thing as in Figure 15.



	90	95	99	Total
Retail	-13,39%	-26,12%	-10,90%	-12,95%
DC	-38,91%	-36,0%	-39,30%	-39,57%

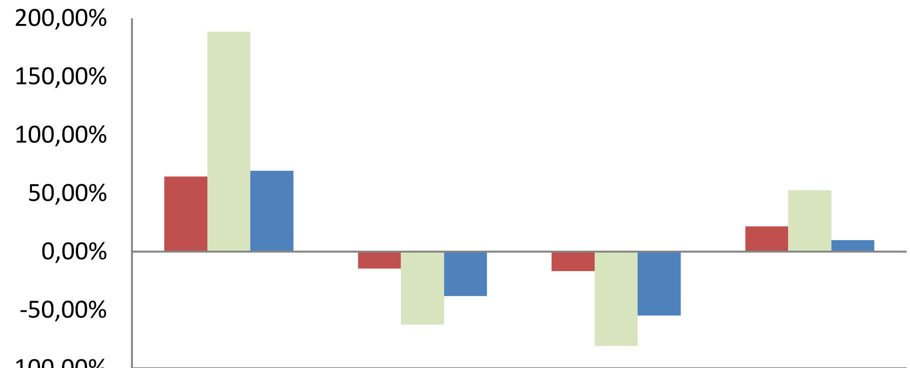
Figure 16: Change in reorder points, divided into service level

In the graph above, it is easy to see that the reorder points are lowered, regardless of service level. There are thus no correlation between service level and reorder point decrease, apart from the slightly larger decrease in retail stores noted for the articles in the 95% class. This is most likely due to chance, and not systematical.

7.3 Inventory levels

As can be assumed from the differences in reorder points that the inventories that are lowered the most are located at the distribution center. This can also be seen in Figure 17. The bars represent the average inventory difference between the approaches for the same articles, according to:

$$\sum_{i=1}^{95} \frac{(Reorder\ point\ for\ article\ i\ with\ Approach\ 1 - Reorder\ point\ for\ article\ i\ with\ Approach\ 2)}{Reorder\ point\ for\ article\ i\ with\ Approach\ 1} \Big/ 95$$

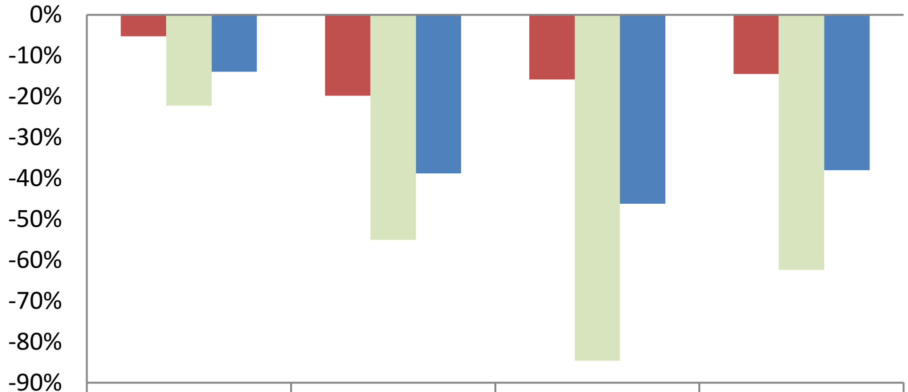


	Group A	Group B	Group C	All
Retail	64,36%	-14,48%	-16,7%	21,63%
DC	188,26%	-62,35%	-80,8%	52,65%
Total	69,19%	-38,04%	-54,8%	9,94%

Figure 17: Change in mean inventory level

The graph above shows that the largest inventory reductions are found in Group C, which is the group that obtained too high present service levels. The fact that the total inventory level is increased is because of the fact that the largest group of articles belongs to Group A, in which the inventory levels are increased significantly, affecting the total more than the other two groups. The reason for the large inventory increase in this group is that the group is far from target service levels with Approach 1. With Approach 2 the inventories are increased to better meet target service.

As for reorder points, the articles in Group B have been divided into service. The results for the different service classes are found in Figure 18.



	90	95	99	Total
Retail	-5,29%	-19,78%	-15,8%	-14,48%
DC	-22,26%	-55,04%	-84,6%	-62,35%
Total	-13,91%	-38,80%	-46,2%	-38,04%

Figure 18: Change in inventory level, service classification

When classifying the articles according to service level, the relation between retail stores, distribution center and total reductions are almost maintained throughout the different classes. What is notable though, is that the reductions are larger with higher service level targets. The total distribution center inventory reductions for the class with highest service target are almost 90 percent, as opposed to 20 percent for the lowest service class. The reason for this is that, as explained earlier, the distribution center does not need a service level at par with the service level at retail stores. So with higher current service levels at the distribution center, larger reductions can be made without losing service to customers.

7.4 Inventory allocation

It is interesting to investigate how the total inventory is distributed between the distribution center and the retail stores. In order to do this, the mean inventory for the distribution center was compared to the average retail inventory, according to:

$$\frac{Mean\ inventory\ at\ DC}{Average\ mean\ inventory\ at\ store\ level}$$

It was found that the distribution center on average keeps 3,14 times more stock than one retail store. To study if any parameters affect the distribution of stock in a systematical way,

S = Target service level
V/M = Relative variance (that is Variance / Mean demand)
MD = Mean demand during one week
LT = Lead time from supplier to DC
L-M-H = Low-Medium-High group

Table 4 was constructed. It shows the inventory relation for different factors if articles are divided into three subgroups within each factor.

S = Target service level
V/M = Relative variance (that is Variance / Mean demand)
MD = Mean demand during one week
LT = Lead time from supplier to DC
L-M-H = Low-Medium-High group

Table 4: Relation between DC inventory and average retail inventory

S	Relation	V/M	Relation	MD	Relation	LT	Relation
90	**2,8**	L	**2,4**	L	**2,4**	L	**1,8**
95	**4,0**	M	**3,0**	M	**2,8**	M	**2,5**
99	**2,4**	H	**3,9**	H	**4,2**	H	**4,9**

From the table above it can be derived that target service level class has no apparent systematical impact on the relation of inventory, since the value for the middle group is larger than the other two. The other three parameters however, seem to influence the relation. More stock will be located at the distribution center, compared to stock at retail level, if:

- The variance of the demand increases in relation to the mean demand
- The mean demand increases
- The lead time between supplier and distribution center is longer

7.5 Inventory costs

To study how the inventory reductions will affect the cost situation at the total inventory system, it is important to include the shortage costs that are the result of not having products available when they are demanded. In Section 4.4 it was explained how the fill rate could be transformed into a shortage cost, with a simple equation, if only the holding cost is known. When calculating the costs below, the formula was used to calculate shortage costs. The holding cost has been set to 1 unit per product and time unit for every article.

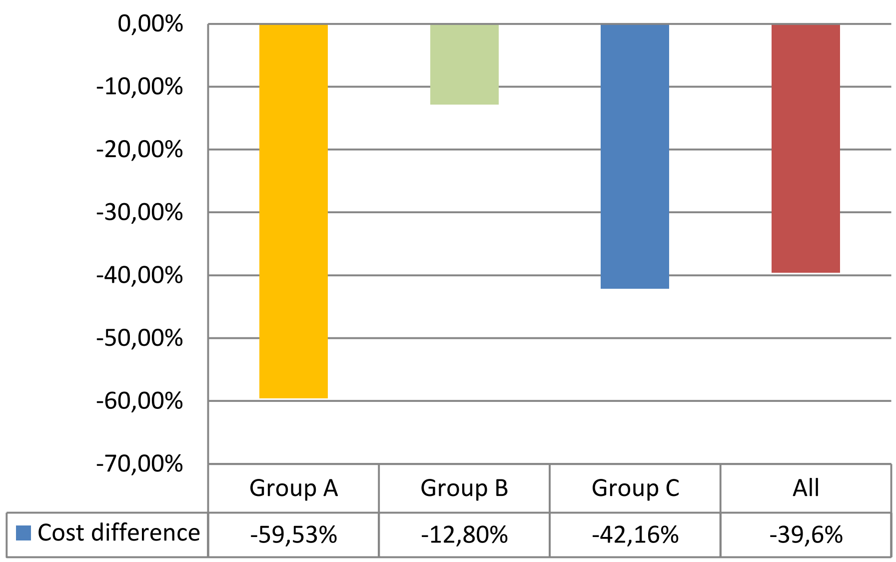
The reason for not using the exact holding cost is that there are many uncertain parameters when determining it. Examples of these parameters are physical packing volume, handling costs and tied up capital cost. Furthermore, it would be difficult to compile the results for all the articles in a comprehensive way. Given that each article shares the same holding cost, the comparison is still valid, and cost reductions can be calculated as percentage points instead of in monetary terms. The results will indicate the potential overall cost reductions.

The total costs per time unit for each article and store was calculated as:

$$\begin{aligned} Total\ cost\ &= Holding\ cost * mean\ inventory + \\ &\quad shortage\ cost * (1 - Serv_2) * \ mean\ demand \end{aligned}$$

The formula above is an approximation of the real cost, since it is derived using the formula for transforming target service level into shortage cost. This transformation assumes a back order system, while the simulation assumes lost sales. This will lead to a slight underestimation of the shortage cost. As the shortages at the distribution center do not affect customer satisfaction, the shortage cost at this level is set to zero. For each article and approach, the costs for every unit were then summarized.
Figure 19 illustrates the average cost reductions for the total inventory for each article, with acceptable service, in percentage:

$$\frac{Total\ cost\ of\ Approach\ 2 - Total\ cost\ of\ Approach\ 1}{Total\ cost\ of\ Approach\ 1}$$



,

Figure 19: Change in inventory costs for each group

The coordinated approach has resulted in a total cost reduction of 39,6% according to the simulation runs. The cost analysis provides an overall image of how the coordinated approach performed since it considers both the inventory reduction and how well the target service was achieved. If only the articles in Group B are included, the average cost reduction is 14,9%. It is notable that the Group A experience the greatest cost reductions, despite the fact that it had increases in inventory levels with Approach 2. This enhances the fact that bad service accuracy affects the total cost greatly. For Group C, the cost reductions follow the inventory decreases using Approach 2.

As for the other comparisons, Group B was divided into target service level groups. The results for these groups are found in Figure 20.

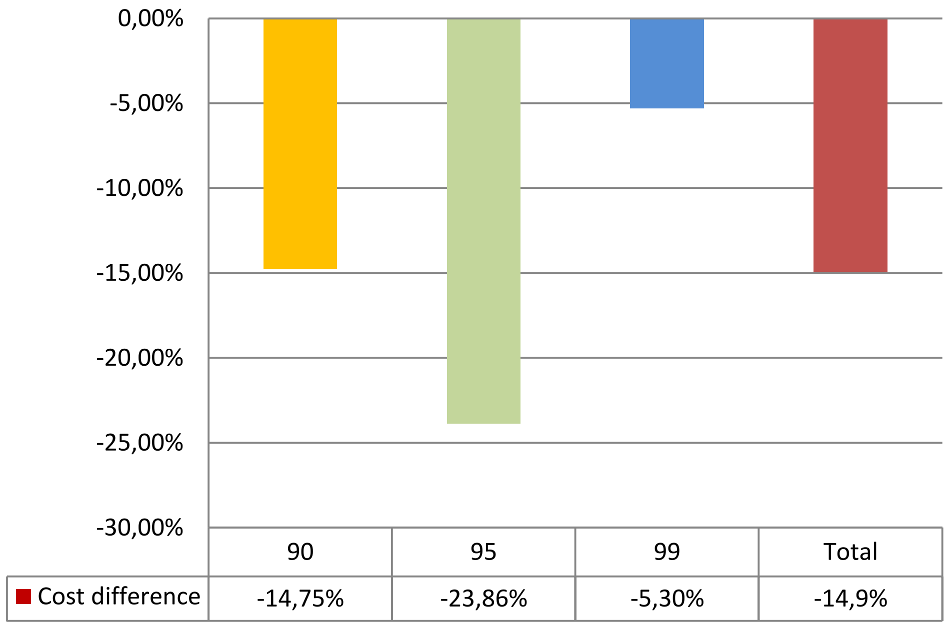


Figure 20: Change in inventory costs, service classification, Group B

As Figure 20 shows there are differences in how large the cost reductions are for the three service classes. The savings in the highest service class are smallest. This is due to the fact that, as seen in Figure 14, the service target is not quite reached for many of the articles in that class. Because the shortage cost is high when the target service is high, this will influence the cost negatively. Similarly, the medium service class performed well in terms of both reaching the service and reducing inventories, which is reflected in the large cost reductions registered for this class. Finally, the lowest service class performs similar to the total average. In this case, the inventory levels were not reduced as much as for the other two classes, and the service target was reached adequately.

7.6 Evaluation of $SERV_{IKEA}$

During the simulations, both $SERV_2$ and $SERV_{IKEA}$ were measured. By doing a comparison of the two, it can be shown how well the measure used today actually captures the service experienced by customers as theoretically defined. In Figure 21, the measured $SERV_2$ and $SERV_{IKEA}$ are plotted. To the left are the results for the simulation runs of Approach 1 and to the right those of Approach 2.

Figure 21: $SERV_2$ and $SERV_{IKEA}$

As seen above, the $SERV_{IKEA}$ measure deviates slightly from $SERV_2$. Most of the deviations seem to be above the fill rate, but there are also cases where $SERV_{IKEA}$ is lower than the fill rate.

In Figure 22 the deviation of each article is plotted. The results of each approach are sorted according to the deviations for Approach 1, and then plotted in the same diagram. The values shown, for each article, are:

$$SERV_{IKEA} - SERV_2$$

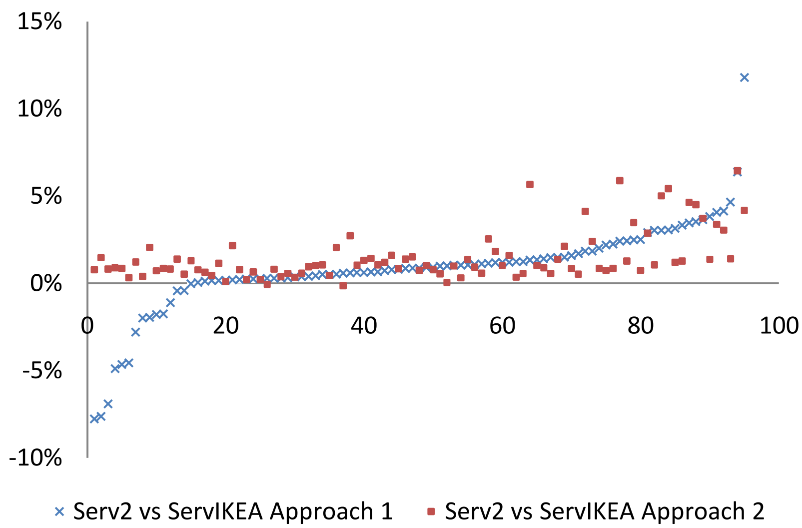


Figure 22: $SERV_{IKEA}$ deviation from $SERV_2$

In the figure above it can be seen that $SERV_{IKEA}$ generally overestimates the actual service. For most articles this overestimation is less than 5%, but for some articles the deviation is larger. Because $SERV_{IKEA}$ is an approximation of $SERV_3$, this positive deviation was expected because customers can order several items at once, as previously explained.

7.6.1 Evaluation of daily $SERV_{IKEA}$

One possible way of improving the results of the $SERV_{IKEA}$ measure might be to measure the service more often. For ten articles, another simulation run was made, this time measuring $SERV_2$, $SERV_{IKEA}$ and a daily $SERV_{IKEA}$. The compilation of the results for the measuring of daily service is found in Appendix 9. How the weekly and daily $SERV_{IKEA}$ performed compared to the fill rate is shown in Figure 23.

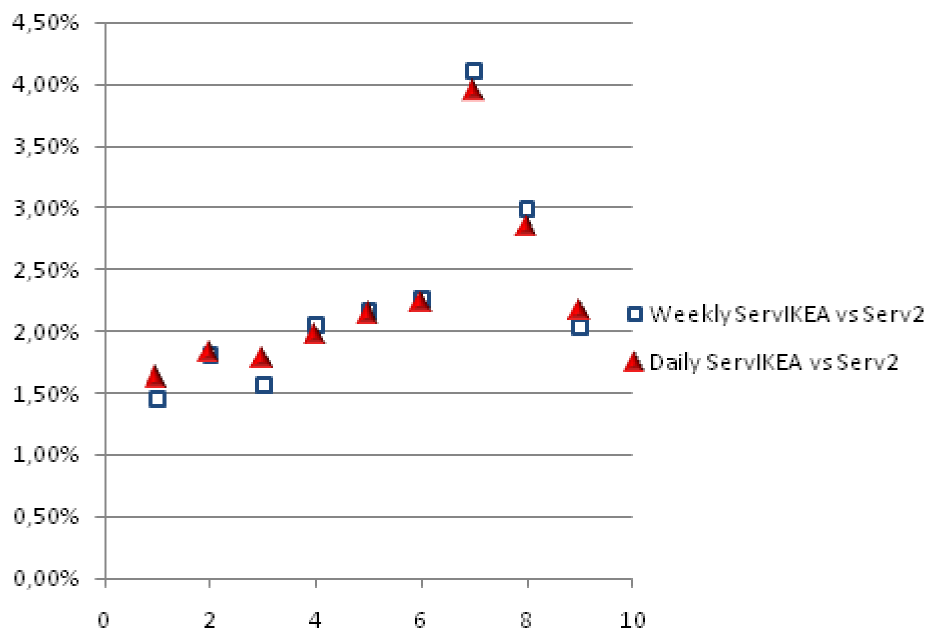


Figure 23: Daily and Weekly SERVIKEA deviations from fill rate

In the graph above it can be seen that the deviations from $SERV_2$ are similar when measuring daily and weekly. It can thus not be concluded that increasing measure intensity increases the accuracy.

8 Discussion

This chapter contains a discussion of the assumptions and approximations done throughout the paper and suggests how the study of a coordinated approach can be improved in the future

In this report, it has been illustrated that a coordinated inventory control approach makes it possible to significantly reduce inventories without lowering the service experienced by customers.

When performing the calculations and comparisons that are the basis of the graphs in the previous chapter, the articles were, as previously explained, divided into several subgroups depending on the system service level for Approach 1. The downside of the classifications is that there were relatively few articles to make the comparisons with in each subgroup and some of the graphs might give a skewed image of reality. The low number of articles makes it more difficult to draw conclusions for the general case. To generalize the conclusions of the study, more articles should be investigated and all data should be collected at the same time. The need for including more articles in a study is due to the large deviations in the service performance of Approach 1. Securing more detailed information on the sales data, daily instead of weekly for example, would also make the results more accurate.

8.1 Differences between the model and reality

During the course of work and throughout the paper there are a number of simplifications and assumptions made when investigating the possible implementation of a coordinated approach to IKEA's supply chain. To give the reader an overview of which these are, in order to build his/her own opinion on the validity of the results, these are now summarized. This section also provides a starting point for possible further studies of the coordinated approach.

8.1.1 Sales data as demand

For practical reasons, the sales data had to be the base for estimating the demand at the retail stores, due to lost sales not being recorded. This leads to an underestimation of the total demand. It might not be possible, but future studies could try to capture lost sales, in order to get the best possible input data.

8.1.2 Lost sales/backorders

In reality it can be assumed that if an article is not available at time of demand, there will be a mixture of lost sales and customers coming back for the item. The range of products available at IKEA is therefore of two kinds: the case where customers buy the product elsewhere and the case when they come back for it later. This, however, is not a backorder, as a customer will not wait for the product, but come back at a different point in time. The analytical model is built on the assumption that the customers wait until the product arrives to the store. The simulation model on the other hand, assumes a lost sale whenever a customer arrives when the stock is empty. This choice is made because it is thought to capture reality in a better way and it will not favor the multi echelon model compared to IKEA's current solution.

8.1.3 Continuous versus periodic review

Both the analytical model used to calculate reorder points and the simulation model assume a continuous reviewing system. This means orders are placed as soon as the inventory reaches the reorder point, R. In reality orders are placed once a day and the inventory position can thus drop below R. A periodic review will affect the service negatively. However, the time between inspections is rather short (once a day) making this problem relatively small. Future studies should take the periodic review that exist in the real case into account and analyze its exact effects.

8.1.4 Fixed order quantities

The investigation of the coordinated approach is based on fixed order quantities. Analyzing the order data shows that order quantities in many cases are not fixed. This is not a big problem since, as mentioned in Section 4.6.1, this has been proven to not affect the results significantly if only the reorder points are adjusted accordingly. Furthermore, processing the data for order quantities showed that fixed minimum order quantities in most cases existed. As explained in section 5.2.3 many of the non-fixed order quantities can be explained with the periodic review system.

8.1.5 Constant lead time

In both models, all transportation times are assumed to be constant. Also, the supplier is assumed to never run out of products. This is something suitable for further studies.

8.2 Final remarks

With the approximation and simplifications set it is worth to mention that all have been applied to the simulation of both approaches, thus not favoring any of them. This makes the investigation and the results still valid, although not exact.

How the implementation of a coordinated approach is practically going to be done is still to be researched. Most of the data is today available to enable the use of the model used in this paper. Some of the data needs to be improved to give more reliable safety stocks, such as mean and variance of demand as well as order quantities. The data used was good enough for the comparison, but needs to be more precise if it is going to be implemented.

9 Conclusions

This final chapter concludes the master's thesis by summarizing the outcomes of the project as well as giving IKEA recommendations on how to proceed with the study on coordinated inventory control

The purpose of this project has been to investigate the effects of a coordinated inventory control system on IKEA's supply chain. This has been done through extracting real historical data from for a sample of high flow articles passing a distribution center and using the UK market as a base for the study. With an analytical model, new reorder points have been calculated for the 95 articles. To evaluate the new reorder points, a simulation model was built in the software Extend. In this model the analytical solution was tested against the current system, investigating mean inventory levels and service levels.

The study of the output parameters shows that when simulating the coordinated case (Approach 2), the service was acceptable at the retail stores, with a few exception articles. That is, the fraction of satisfied customers was close to the target service. This means that despite the assumption of normal demand made in the analytical model, the reorder points are still valid for a more generalized and probable customer demand.

It became apparent that simulating the current situation (Approach 1) using the IKEA system's suggestion of safety days gave varying results. The service levels in the simulation with Approach 1 were in half of the cases unreasonably far from the target service. This made the comparison to the coordinated approach difficult to overview and the articles were therefore divided into three different groups depending on how the system service deviated from the target. The group most suitable for comparisons is the group with the most accurate service with Approach 1.

For this group, the service measured at the distribution center was much lower with the coordinated approach, 49,3% in average, compared to 82,7% for

Approach 1. A low service at the distribution center was also expected. It is important to remember that the service experienced by retail stores is not important, as long as it does not affect the availability of products to end customers. Shortages in themselves at distribution centers are not devastating.

For the same group, a comparison of the reorder points for Approach 1 with the ones calculated for Approach 2 shows that, at DC level, they were significantly lower with Approach 2. The difference at the retail stores was not as large in relative terms. The results from the simulations confirmed what was expected to happen: the inventory level and the measured service at the distribution center were much lower with the coordinated approach. The reduction at the DC was 62,4% if only articles with most accurate service levels are considered. The inventories at the retail stores were reduced with 14,5% with Approach 2, giving a total reduction of 38,0%. This means that the costs associated with keeping stock are also reduced, such as space, handling and tied up capital costs.

The same comparison for when the system service with Approach 1 was more than 5 percentage points below target service indicates that the coordinated approach is appropriate from another point of view. The reorder points and the inventories increased a lot with the coordinated approach, but so did the service. This indicates that the current system is far from optimizing the inventories and requires manual adjustments in order to keep service at acceptable levels.

The total cost for an inventory system evaluates both the mean inventory and the system service as it sums the holdings costs and the shortage costs. The coordinated approach was shown in this paper to reduce inventory costs with 14,9% if only articles with most accurate service are considered. If the total inventory cost is assumed to be somewhat linear to the volume, this is an indication of the possible savings that a coordinated approach would lead to if implemented. If all articles are considered, the average cost reduction is 39,6%.

The method currently used to measure service works relatively well. According to the results from the simulation, it generally gives a higher value than the theoretical definition for $SERV_2$. This means that the fraction of demand that can be taken directly from stock is lower in reality than the current measured service shows. Measuring service by checking the inventories daily has also been investigated through simulation, but showed no significant improvement from measuring weekly. The additional costs for the daily measure do not increase the precision, and is therefore not to recommend. A suggestion to improve the measurement is to try to find a way to capture the number of lost sales due to shortages.

We recommend IKEA to continue prestudy the possibilities to implement a coordinated inventory control to the articles passing through distribution centers. Implementing the approach will reduce the total inventory cost which in turn also affects other inventory decisions, such as the fraction of direct delivery to have. The most obvious areas to continue with the studies are to improve the quality of the input parameters and to improve the comparison with the current system. The data should be collected for a longer period of time, demand data should be on daily basis and order quantities more accurate. This will lead to a more precise and reliable base for an eventual decision to use the coordinated approach.

One of the biggest advantages with implementing the approach is that the savings are large, but the investments are not. No new equipment or changed routines are required, only a different way of calculating reorder points.

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Appendix 1: Analytical model interface

PROBLEM DATA AND RESULTS

D_warehouse_new			
pdfmax	*k*	*pdfN(k)*	*F(k)*
88	48	8,4E-05	0,999975
		tolerans:	0,000100

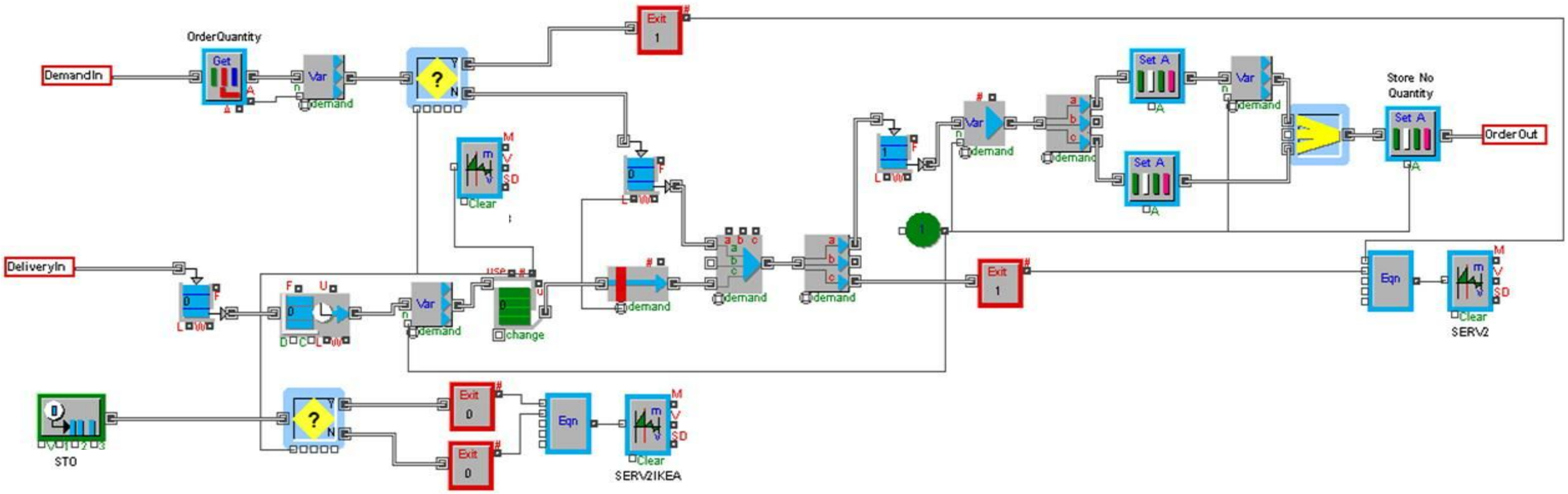
Problem Data: Initialize Run

No. of Retailers (N)=	17	
CW_demand =	1	(see possible choices to the right)
Choice =	3	
DMEIC II_complex = 1	(Normal demand, Q0>=max(Qi), R0>=-Q, komplex ledtidsapprox)	
DMEIC II_simple = 2	(Normal demand, Q0>=max(Qi), R0>=-Q, enkel ledtidsapprox)	
Berling_Marklund_E =3	(Normal demand, pi>=1, using β_BM,E as induced backorder cost)	
Berling_Marklund_T =4	(Normal demand, pi>=1, using β_BM,T as induced backorder cost)	

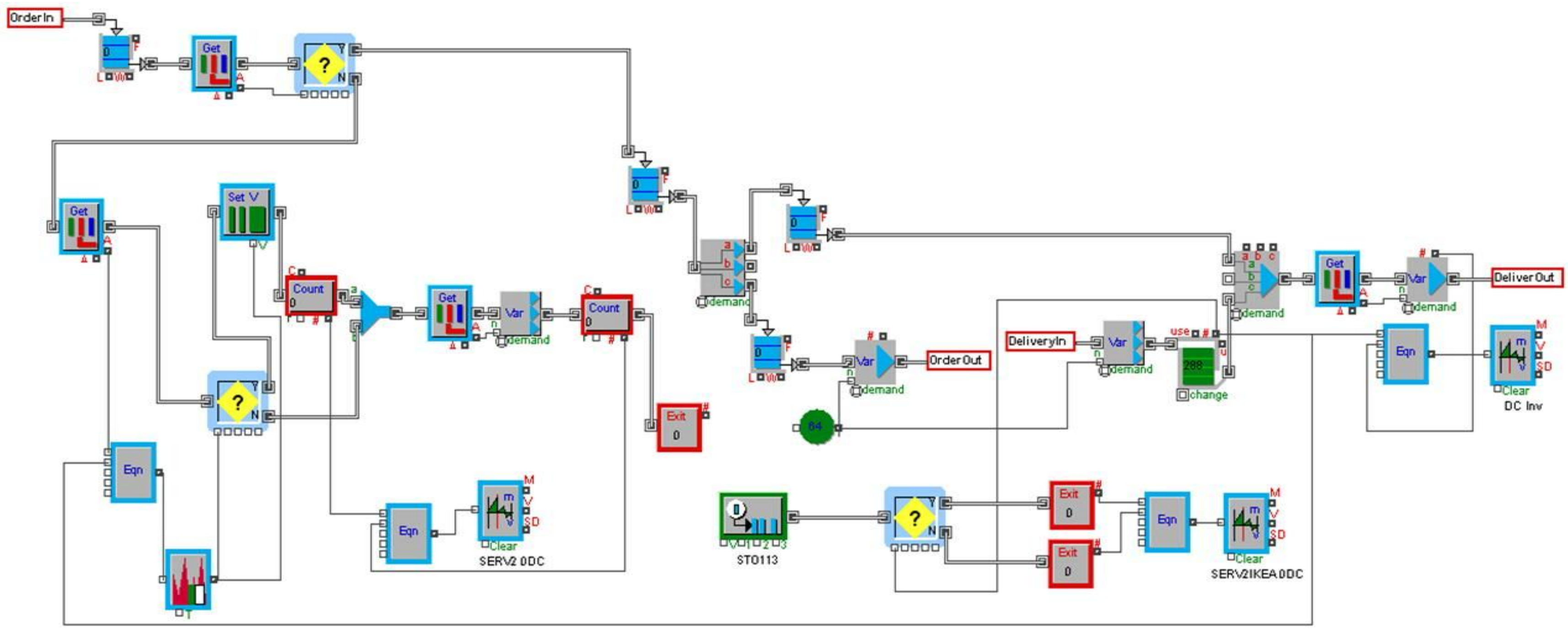
CW_demand choices	
D_warehouse	= 0
D_warehouse_new	= 1
D_warehouse_N_approx	= 2
D_warehouse_Gamma	= 3

	Min Batch quantity **Q**	Order Quantity (in batches of Q) **Q0, qi**	Trp time **L**	Holding cost **h**	Shortage cost **p**	Demand/time unit: Mean **my**	Demand/time unit: Std. Dev **sigma**	Target Fillrate	**R0, Ri**	
Warehouse	320	3	9,85714	1					33	Warehouse
Retailer No.										Retailer No.
1	320	1	0,42857	1	99	21,2692	23,63	99%	42,61711121	1
2	320	1	0,28571	1	99	26,0192	54,69	99%	88,25335693	2
3	320	1	0,28571	1	99	101,038	98,57	99%	238,2688599	3
4	320	1	0,28571	1	99	35,8462	25,40	99%	53,80746841	4
5	320	1	0,28571	1	99	30,4231	22,93	99%	45,3547821	5
6	320	1	0,28571	1	99	214,788	126,65	99%	402,1128845	6
7	320	1	0,28571	1	99	11,5577	14,77	99%	17,44274521	7
8	320	1	0,28571	1	99	48,4231	35,30	99%	79,78327942	8
9	320	1	0,28571	1	99	43,6538	32,02	99%	70,44265747	9
10	320	1	0,28571	1	99	217,885	86,90	99%	329,9479675	10
11	320	1	0,28571	1	99	19	24,96	99%	36,91851044	11
12	320	1	0,28571	1	99	122,865	72,80	99%	212,7602539	12
13	320	1	0,28571	1	99	69,2115	47,22	99%	118,0599289	13
14	320	1	0,28571	1	99	87,1731	44,08	99%	130,5430298	14
15	320	1	0,28571	1	99	48,25	21,16	99%	60,39800644	15
16	320	1	0,28571	1	99	79,8269	29,00	99%	101,2597733	16
17	320	1	0,28571	1	99	29,9808	18,32	99%	39,27886581	17

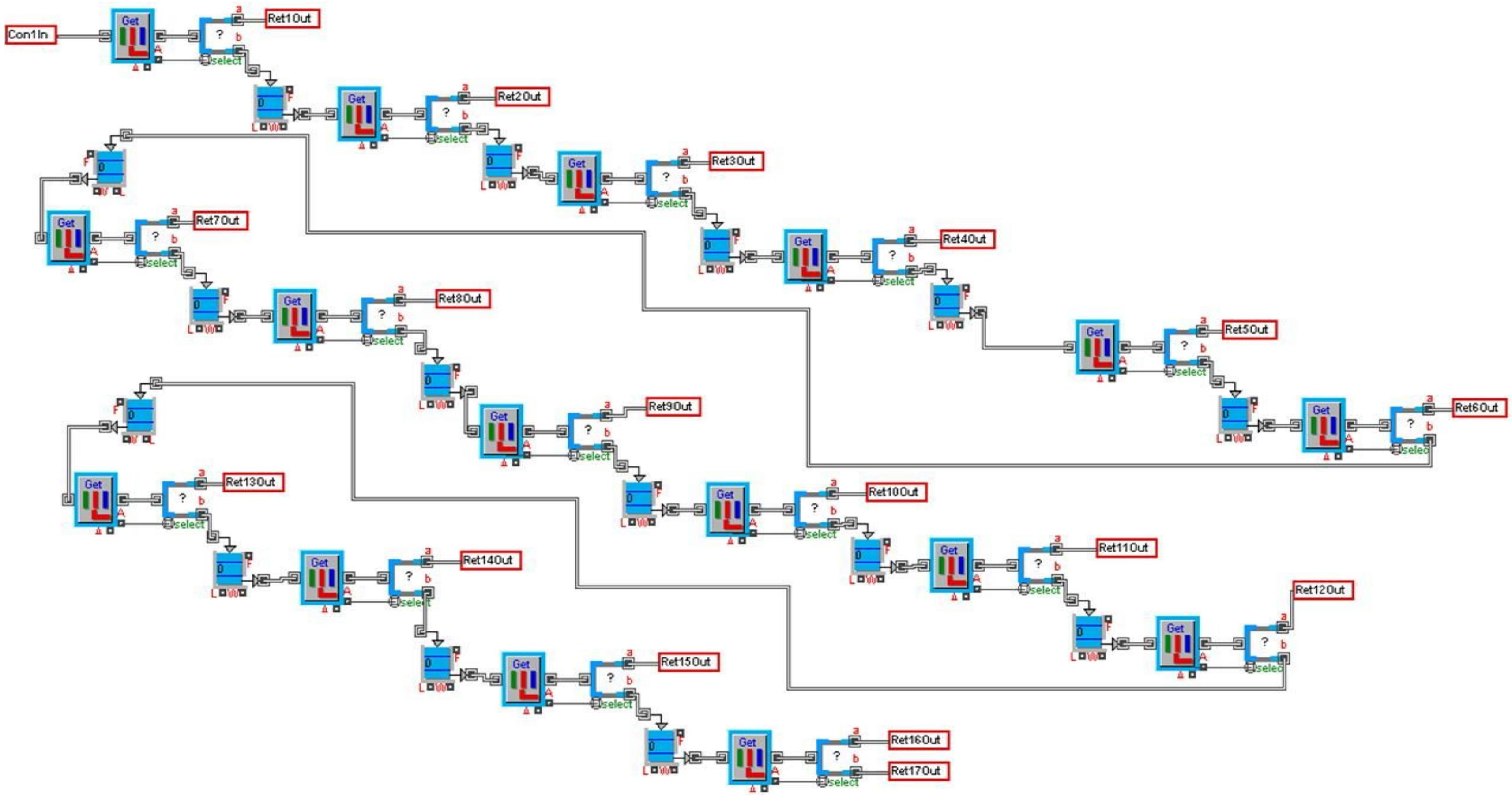
Appendix 2: Extend model: retail store



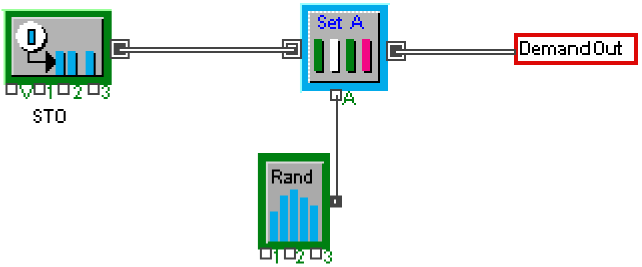
Appendix 3: Extend model: Distribution center

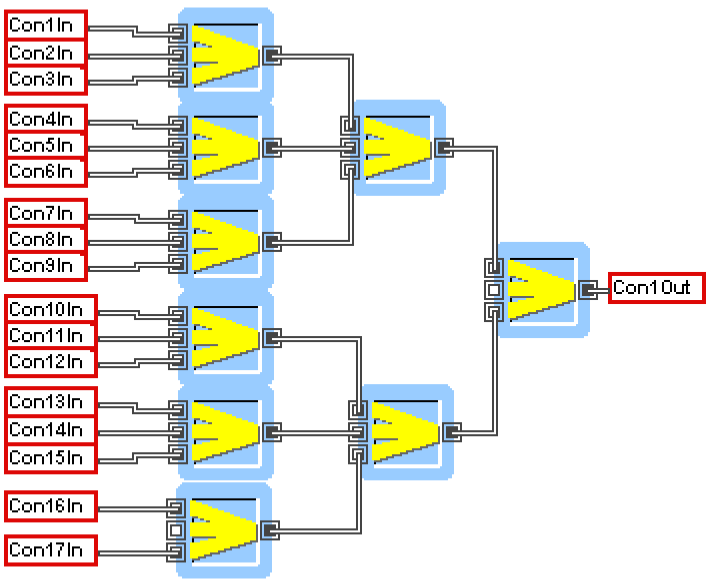


Appendix 4: Extend model: Deciding which store



Appendix 5: Extend model: Generator and Merge





Appendix 6: Compilation of results

After running both the analytical model and the Extend model, the results were inserted into an Excel-sheet. This is attached below. The following abbreviations are used:

List of abbreviations:

LT	Lead time class, lead time between supplier and DC
Fr	Frequency class, mean demand
V/M	Variance / Mean class, relation between variance of demand and mean demand
S	Service class, target service
A	Difference in reorder point between Approach 1 and 2, in percent in average on retail level
B	Difference in reorder point between Approach 1 and 2, in percent on DC level
C	Inventory difference, in percent in average on retail level
D	Inventory difference, in percent on DC level
E	Inventory difference, in percent in total
F	Mean inventory with approach 2, DC level
G	Average mean inventory with approach 2, retail level
H	Relationship between DC inventory and retail inventory for Approach 2
I	Cost difference of total system, in percent
J	Difference between the two approaches in $SERV_2$ in percentage points (approach 1 – approach 2)
K	Difference between the two approaches in $SERV_{IKEA}$ in percentage points (approach 1 – approach 2)
L	$SERV_2$ deviation from target, Approach 1
M	$SERV_2$ deviation from target, Approach 2
N	Service level at DC level, Approach 1
O	Service level at DC level, Approach 2
P	Difference between $SERV_2$ and $SERV_{IKEA}$, Approach 1
Q	Difference between $SERV_2$ and $SERV_{IKEA}$, Approach 2

Article number	LT	Fr	V/M	S	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
XXXXXX	H	H	H	H	43%	80%	22%	96%	29%	1732,92	647,81	2,68	-69%	18%	18%	-20%	-2%	24%	42%	-1%	0%
XXXXXX	H	H	H	M	3%	9%	-19%	7%	-15%	289,77	83,15	3,48	-33%	7%	6%	-7%	0%	51%	52%	-1%	-1%
XXXXXX	H	H	M	L	-18%	-19%	-12%	-89%	-56%	70,43	24,28	2,90	-45%	-4%	3%	9%	4%	99%	51%	7%	-1%
XXXXXX	L	M	M	H	-47%	-55%	-14%	-96%	-65%	23,43	18,15	1,29	-12%	-3%	-2%	0%	-3%	99%	42%	-1%	-2%
XXXXXX	L	M	M	H	-35%	-32%	-37%	-94%	-57%	7,75	9,28	0,84	24%	-3%	-2%	1%	-2%	100%	43%	0%	-1%
XXXXXX	L	M	L	H	-56%	-105%	35%	-86%	-48%	40,32	10,81	3,73	64%	-8%	-9%	-1%	-10%	100%	52%	-1%	-1%
XXXXXX	L	L	L	M	-50%	-60%	-10%	-96%	-45%	7,22	12,95	0,56	-32%	-5%	-5%	4%	-1%	97%	33%	0%	0%
XXXXXX	M	L	L	M	160%	230%	111%	931%	166%	20,91	3,52	5,94	-80%	51%	51%	-50%	2%	25%	77%	-1%	-1%
XXXXXX	L	M	M	H	-44%	-54%	-6%	-94%	-61%	18,30	9,05	2,02	0%	-3%	-3%	0%	-4%	100%	53%	-1%	-1%
XXXXXX	M	L	M	L	-29%	-16%	-8%	-68%	-14%	7,62	11,99	0,64	-12%	-1%	-2%	3%	2%	49%	36%	-2%	-1%
XXXXXX	H	M	L	L	26%	25%	26%	90%	36%	36,37	8,38	4,34	-13%	13%	13%	-9%	4%	45%	64%	-1%	-1%
XXXXXX	M	L	L	M	4%	14%	-7%	186%	2%	9,05	3,49	2,60	-14%	4%	3%	-3%	0%	41%	70%	-1%	-1%
XXXXXX	M	H	M	M	30%	28%	51%	55%	52%	66,81	14,94	4,47	-64%	23%	20%	-23%	0%	59%	65%	-4%	-1%
XXXXXX	H	H	L	M	24%	33%	-10%	31%	1%	91,57	10,72	8,54	-70%	22%	22%	-21%	1%	66%	73%	-1%	-1%
XXXXXX	H	M	M	M	32%	34%	38%	148%	53%	51,20	10,10	5,07	-55%	18%	17%	-19%	-1%	50%	64%	-2%	-1%
XXXXXX	L	L	L	M	-63%	-67%	-25%	-95%	-48%	2,87	4,79	0,60	-39%	-5%	-5%	5%	-1%	97%	35%	0%	-1%
XXXXXX	H	M	L	H	48%	51%	79%	262%	105%	62,77	10,69	5,87	-83%	24%	23%	-26%	-2%	49%	61%	-2%	-1%
XXXXXX	H	H	H	H	23%	13%	79%	-35%	15%	1586,04	202,50	7,83	-48%	11%	10%	-20%	-8%	80%	66%	-1%	0%
XXXXXX	L	M	M	H	-45%	-50%	-23%	-98%	-70%	11,60	17,64	0,66	-10%	-3%	-3%	0%	-3%	99%	38%	0%	-1%
XXXXXX	H	L	M	L	17%	44%	0%	124%	11%	24,08	6,46	3,73	-4%	8%	9%	-8%	0%	38%	70%	-3%	-5%
XXXXXX	L	H	H	L	-53%	-54%	-43%	-96%	-81%	55,15	18,36	3,00	-66%	-7%	-5%	9%	2%	100%	60%	0%	-2%
XXXXXX	L	H	H	M	-26%	2%	-39%	11%	-37%	213,74	165,12	1,29	-18%	-2%	-2%	1%	-2%	29%	36%	0%	-1%
XXXXXX	L	M	M	H	-40%	-39%	-45%	-99%	-74%	5,45	11,13	0,49	-5%	-3%	-2%	1%	-2%	100%	32%	0%	-1%
XXXXXX	M	M	M	H	-33%	-43%	-7%	-92%	-54%	28,58	15,09	1,89	22%	-4%	-4%	0%	-4%	100%	48%	0%	-1%
XXXXXX	H	H	H	H	33%	37%	44%	223%	59%	127,11	36,91	3,44	-75%	17%	20%	-20%	-3%	36%	53%	2%	0%
XXXXXX	H	M	M	M	271%	396%	130%	122%	129%	28,84	9,86	2,92	-63%	47%	55%	-46%	1%	20%	62%	8%	-1%
XXXXXX	M	M	H	L	-29%	-39%	-7%	-75%	-39%	70,09	17,65	3,97	-21%	-5%	-5%	3%	-2%	98%	60%	-4%	-4%
XXXXXX	M	M	L	L	-88%	-155%	73%	-74%	-43%	295,10	30,00	9,84	-27%	-16%	-18%	4%	-11%	99%	70%	-3%	-1%
XXXXXX	H	H	H	M	-3%	3%	-48%	12%	-38%	373,38	50,86	7,34	-33%	2%	4%	-2%	0%	61%	68%	2%	-1%
XXXXXX	M	H	H	M	20%	36%	-1%	96%	7%	948,31	332,43	2,85	-51%	14%	14%	-14%	0%	27%	51%	-1%	-1%
XXXXXX	H	H	H	M	104%	109%	128%	529%	187%	192,05	23,49	8,17	-61%	38%	38%	-39%	-1%	44%	78%	-3%	-3%

Article number	LT	Fr	V/M	S	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
XXXXXX	L	M	M	H	-85%	-93%	6%	-99%	-87%	13,96	8,72	1,60	-63%	0%	-1%	-5%	-5%	100%	56%	-4%	-3%
XXXXXX	M	M	M	M	-20%	-25%	0%	-88%	-44%	30,17	14,61	2,07	-18%	-3%	-3%	2%	-1%	100%	52%	-1%	-1%
XXXXXX	M	H	M	H	124%	128%	186%	52%	136%	158,81	29,40	5,40	-87%	45%	44%	-49%	-4%	66%	57%	-2%	-1%
XXXXXX	L	L	M	M	-44%	-45%	-23%	-85%	-52%	13,10	4,46	2,94	-26%	-5%	-3%	0%	-5%	100%	74%	-3%	-5%
XXXXXX	M	L	L	M	-44%	-40%	-24%	-86%	-45%	6,70	4,15	1,61	-32%	-4%	-4%	2%	-2%	99%	61%	-2%	-2%
XXXXXX	M	M	L	L	63%	47%	18%	46%	18%	16,50	27,83	0,59	5%	9%	9%	-8%	2%	22%	26%	0%	0%
XXXXXX	L	L	L	M	-32%	-37%	-12%	-82%	-24%	5,65	8,23	0,69	-10%	-4%	-4%	3%	-1%	75%	35%	0%	0%
XXXXXX	H	H	M	H	231%	219%	225%	267%	231%	129,96	34,81	3,73	-88%	48%	50%	-51%	-3%	44%	50%	2%	-1%
XXXXXX	L	H	H	L	-53%	-66%	-27%	-76%	-35%	62,52	54,49	1,15	-23%	-7%	-7%	6%	0%	79%	17%	0%	0%
XXXXXX	H	H	H	M	92%	107%	92%	602%	154%	758,47	88,76	8,54	-79%	40%	40%	-40%	1%	46%	72%	-1%	-1%
XXXXXX	H	H	H	H	95%	78%	29%	10%	28%	483,64	390,30	1,24	-54%	19%	18%	-21%	-3%	32%	47%	-2%	-1%
XXXXXX	M	L	L	H	-39%	-50%	-12%	-89%	-37%	5,45	5,27	1,03	-26%	-1%	-1%	-1%	-1%	98%	52%	-1%	-1%
XXXXXX	H	M	M	H	9%	5%	22%	-32%	7%	61,12	17,00	3,59	-47%	6%	6%	-9%	-3%	70%	57%	-1%	0%
XXXXXX	L	L	L	H	-53%	-55%	-29%	-92%	-49%	4,86	5,57	0,87	-25%	-3%	-2%	1%	-2%	98%	48%	0%	-1%
XXXXXX	H	H	M	H	277%	295%	414%	412%	414%	126,53	25,01	5,06	-92%	60%	65%	-63%	-3%	52%	53%	5%	0%
XXXXXX	M	M	H	H	15%	1%	41%	-41%	26%	32,40	20,15	1,61	-51%	6%	3%	-9%	-3%	78%	52%	-5%	-1%
XXXXXX	M	M	H	H	-11%	-36%	41%	-66%	-20%	140,18	26,07	5,38	-40%	7%	0%	-14%	-7%	99%	73%	-12%	-4%
XXXXXX	H	M	M	H	28%	27%	41%	76%	46%	49,29	13,27	3,72	-73%	16%	15%	-19%	-3%	45%	57%	-2%	-1%
XXXXXX	H	L	M	L	-57%	-224%	-8%	-62%	-27%	55,53	14,28	3,89	-22%	-6%	-7%	1%	-5%	75%	62%	-1%	0%
XXXXXX	M	L	L	H	1%	2%	1%	-30%	-2%	10,77	6,96	1,55	-26%	3%	3%	-5%	-2%	55%	53%	0%	0%
XXXXXX	H	H	H	M	139%	173%	103%	313%	147%	677,75	73,99	9,16	-62%	43%	44%	-46%	-3%	60%	68%	0%	-1%
XXXXXX	M	H	H	H	39%	81%	-31%	76%	-29%	37,62	47,44	0,79	-88%	33%	35%	-35%	-2%	23%	36%	1%	-1%
XXXXXX	H	M	M	H	73%	88%	140%	738%	170%	39,68	12,52	3,17	-87%	34%	32%	-37%	-3%	26%	53%	-3%	-1%
XXXXXX	M	L	L	M	-22%	-16%	-20%	-68%	-27%	11,48	9,87	1,16	-9%	-4%	-4%	4%	0%	77%	47%	0%	-1%
XXXXXX	L	H	H	M	-34%	-40%	-19%	-89%	-51%	61,94	32,58	1,90	-14%	-5%	-5%	3%	-2%	99%	44%	-1%	-1%
XXXXXX	L	L	L	L	-63%	-66%	-31%	-86%	-50%	7,20	3,92	1,84	-33%	-8%	-7%	8%	-1%	100%	46%	-1%	-3%
XXXXXX	M	L	L	H	-41%	-54%	-2%	-94%	-47%	6,40	6,74	0,95	-26%	-1%	-2%	-1%	-2%	99%	46%	-1%	-1%
XXXXXX	L	M	M	H	-61%	-70%	-17%	-98%	-65%	6,02	10,40	0,58	-30%	-3%	-2%	0%	-3%	99%	39%	0%	-1%
XXXXXX	H	H	H	H	150%	178%	87%	51%	83%	421,91	230,59	1,83	-86%	42%	40%	-44%	-2%	26%	49%	-2%	-1%
XXXXXX	M	L	L	H	-20%	-21%	-15%	-76%	-28%	7,07	5,24	1,35	2%	-3%	-2%	-1%	-3%	92%	58%	-1%	-2%
XXXXXX	H	L	L	M	93%	133%	75%	544%	105%	23,14	5,38	4,30	-58%	33%	33%	-33%	0%	27%	72%	-1%	-1%
XXXXXX	H	M	M	H	56%	51%	123%	179%	134%	72,56	14,89	4,87	-80%	25%	29%	-27%	-2%	52%	65%	3%	-1%

Article number	LT	Fr	V/M	S	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
XXXXXX	M	L	L	L	-61%	-68%	-28%	-89%	-66%	17,46	4,01	4,35	-55%	-9%	-7%	8%	-1%	100%	63%	-1%	-3%
XXXXXX	L	M	H	L	-76%	-82%	-19%	-97%	-78%	31,00	14,16	2,19	-62%	-8%	-7%	5%	-2%	100%	51%	-2%	-3%
XXXXXX	M	L	L	M	-19%	-15%	-16%	-58%	-21%	11,56	10,39	1,11	-5%	-3%	-2%	3%	0%	65%	46%	-1%	-1%
XXXXXX	L	L	M	L	-95%	-117%	-32%	-91%	-72%	20,45	4,37	4,68	-58%	-13%	-10%	7%	-5%	100%	56%	-2%	-4%
XXXXXX	M	L	M	L	-39%	-25%	-15%	-51%	-16%	6,16	11,65	0,53	-12%	-5%	-4%	6%	1%	46%	32%	-1%	-1%
XXXXXX	L	M	M	H	27%	27%	36%	71%	38%	13,66	9,34	1,46	-69%	12%	10%	-16%	-3%	32%	50%	-3%	-1%
XXXXXX	L	L	L	M	-43%	-51%	-6%	-86%	-47%	13,63	5,34	2,55	-35%	-1%	-1%	-1%	-2%	100%	67%	-4%	-3%
XXXXXX	M	H	H	H	146%	354%	168%	-61%	135%	15,37	36,36	0,42	-91%	45%	50%	-47%	-3%	9%	34%	5%	-1%
XXXXXX	M	L	H	L	78%	139%	29%	336%	61%	66,32	9,80	6,76	-8%	22%	22%	-24%	-2%	49%	80%	-6%	-6%
XXXXXX	M	M	M	L	60%	87%	52%	164%	60%	25,38	11,34	2,24	-48%	25%	29%	-23%	2%	16%	58%	2%	-2%
XXXXXX	H	H	H	L	-20%	-20%	-16%	-81%	-46%	85,23	25,16	3,39	-33%	-5%	-4%	7%	2%	99%	61%	-2%	-2%
XXXXXX	L	L	M	L	-8%	51%	-24%	169%	-16%	10,29	4,12	2,50	-22%	5%	6%	-6%	-2%	24%	61%	-4%	-4%
XXXXXX	L	L	L	M	-60%	-69%	-11%	-92%	-54%	11,41	6,65	1,72	-39%	-5%	-4%	3%	-2%	100%	45%	-1%	-2%
XXXXXX	L	M	L	H	-11%	-9%	-15%	-66%	-19%	7,21	12,12	0,59	48%	-2%	-1%	0%	-2%	64%	39%	0%	-1%
XXXXXX	H	M	M	M	146%	169%	130%	311%	156%	56,60	11,15	5,08	-68%	40%	49%	-40%	0%	36%	68%	8%	-1%
XXXXXX	M	L	L	H	-11%	-14%	-4%	-59%	-12%	10,49	8,45	1,24	-2%	-1%	0%	-1%	-2%	70%	48%	0%	-1%
XXXXXX	H	M	M	M	38%	48%	25%	270%	61%	85,60	10,03	8,53	-60%	21%	21%	-21%	0%	42%	75%	-1%	-1%
XXXXXX	M	M	L	M	73%	93%	73%	627%	102%	22,04	5,51	4,00	-76%	35%	35%	-33%	1%	25%	70%	-1%	-1%
XXXXXX	H	H	H	L	-3%	4%	-20%	-10%	-19%	858,56	259,87	3,30	-21%	3%	2%	2%	5%	50%	51%	-1%	0%
XXXXXX	H	H	H	L	9%	14%	1%	0%	1%	1015,59	253,46	4,01	-11%	6%	7%	-3%	4%	48%	54%	-1%	-1%
XXXXXX	L	L	L	M	-89%	-109%	-41%	-84%	-66%	18,42	2,68	6,87	-50%	-8%	-4%	1%	-7%	100%	72%	-1%	-6%
XXXXXX	L	M	L	H	-73%	-76%	-50%	-98%	-85%	6,82	4,55	1,50	-80%	13%	14%	-16%	-3%	100%	57%	0%	-1%
XXXXXX	M	L	L	H	-39%	-46%	-13%	-93%	-51%	6,91	5,67	1,22	-15%	-2%	-2%	0%	-2%	100%	52%	-1%	-1%
XXXXXX	M	H	M	M	73%	100%	49%	112%	54%	40,32	19,79	2,04	-65%	28%	34%	-29%	-1%	16%	53%	5%	-1%
XXXXXX	M	L	L	L	22%	27%	10%	82%	14%	24,11	14,24	1,69	0%	7%	8%	-5%	3%	32%	46%	0%	-1%
XXXXXX	H	H	H	M	5%	12%	34%	227%	57%	1704,38	307,19	5,55	-9%	8%	8%	-5%	3%	44%	55%	-1%	-1%
XXXXXX	L	M	L	M	-19%	-21%	-13%	-82%	-24%	5,43	8,74	0,62	-5%	-3%	-3%	3%	0%	79%	35%	0%	0%
XXXXXX	L	L	H	L	-79%	-85%	-3%	-96%	-77%	23,37	7,94	2,94	-70%	-9%	-6%	5%	-3%	100%	62%	-3%	-5%
XXXXXX	L	L	L	L	-33%	-12%	-27%	-36%	-28%	5,37	6,49	0,83	-16%	-6%	-5%	7%	1%	52%	40%	-1%	-2%
XXXXXX	L	M	H	L	-52%	-51%	-35%	-91%	-64%	31,28	12,06	2,59	-50%	-8%	-4%	6%	-2%	100%	63%	-2%	-6%
XXXXXX	H	H	H	M	48%	55%	47%	431%	82%	171,42	27,51	6,23	-67%	25%	26%	-26%	0%	41%	70%	-1%	-2%
XXXXXX	M	H	H	H	-8%	-7%	-27%	-82%	-57%	704,97	148,40	4,75	-60%	4%	4%	-6%	-2%	95%	53%	0%	0%

Appendix 7: Example of indata table

XXXXXX	Min order quantity	Number of Q ordered each time	Lead time	Holding cost	Shortage cost	Mean demand during a week	Standard deviation during a week	Inter-arrival mean	Variance / mean		Target fill-rate
Storenumber	Q	Q0,qi	L	h	b	My	Sigma	lambda		Alpha	S
DC	15	7	11	1		120,1					
STO1	15	1	0,43	1	19	14,2	9,5	0,2	6,3	0,8	95%
STO2	15	1	0,29	1	19	2,0	2,3	0,8	2,7	0,6	95%
STO3	15	1	0,29	1	19	18,2	7,0	0,1	2,7	0,6	95%
STO4	15	1	0,29	1	19	11,2	6,0	0,2	3,2	0,7	95%
STO5	15	1	0,29	1	19	7,3	4,1	0,2	2,4	0,6	95%
STO6	15	1	0,29	1	19	9,9	9,3	0,4	8,7	0,9	95%
STO7	15	1	0,29	1	19	4,7	2,9	0,3	1,8	0,5	95%
STO8	15	1	0,29	1	19	6,9	3,6	0,2	1,8	0,4	95%
STO9	15	1	0,29	1	19	2,3	1,7	0,5	1,3	0,2	95%
STO10	15	1	0,29	1	19	12,0	6,9	0,2	4,0	0,7	95%
STO11	15	1	0,29	1	19	6,2	4,5	0,3	3,3	0,7	95%
STO12	15	1	0,29	1	19	7,4	4,3	0,2	2,5	0,6	95%
STO13	15	1	0,29	1	19	2,3	1,5	0,4	1,0	0,0	95%
STO14	15	1	0,29	1	19	3,2	2,4	0,4	1,8	0,4	95%
STO15	15	1	0,29	1	19	3,5	2,5	0,4	1,7	0,4	95%
STO16	15	1	0,29	1	19	5,5	3,4	0,3	2,1	0,5	95%
STO17	15	1	0,29	1	19	3,4	2,8	0,5	2,2	0,6	95%

Article number	Leadtime	Leadtime class	Frequency	Frequency class	Variance / mean	Variance/mean - class	Service requirement	Service class
XXXXXX	11	High	7	Medium	3,55928	Medium	95%	Middle

XXXXXX	Reorder point Approach 1	Reorder point Approach 2	Total order quantity	Reorder point Approach 1	Reorder point Approach 2	Maximum inventory Approach 1	Maximum inventory Approach 2	Weighted Variance/mean value	Safety weeks	Min SS
Storenumber	R old	R new	Q (units)	R old (units)	R new (units)	R + Q	R + Q		w (weeks)	
DC	463,4	*83,0*	105	463	1245	568	1350		3,86	
STO1	8,0	*18,7*	15	8	19	23	34	0,75	0,35	8
STO2	3,0	*1,2*	15	3	1	18	16	0,05	0,50	3
STO3	6,9	*15,4*	15	7	15	22	30	0,41	0,38	6
STO4	5,5	*9,9*	15	5	10	20	25	0,30	0,49	4
STO5	4,0	*5,8*	15	4	6	19	21	0,14	0,42	4
STO6	9,0	*12,7*	15	9	13	24	28	0,72	0,45	9
STO7	4,0	*3,3*	15	4	3	19	18	0,07	0,48	4
STO8	7,0	*5,1*	15	7	5	22	20	0,10	0,37	7
STO9	4,0	*1,0*	15	4	1	19	16	0,02	0,49	4
STO10	10,0	*11,3*	15	10	11	25	26	0,39	0,33	10
STO11	6,0	*5,4*	15	6	5	21	20	0,17	0,53	6
STO12	4,0	*6,1*	15	4	6	19	21	0,15	0,49	4
STO13	3,0	*1,0*	15	3	1	18	16	0,02	0,51	3
STO14	3,0	*2,0*	15	3	2	18	17	0,05	0,49	3
STO15	4,0	*2,2*	15	4	2	19	17	0,05	0,48	4
STO16	3,0	*4,1*	15	3	4	18	19	0,10	0,49	3
STO17	3,0	*2,4*	15	3	2	18	17	0,06	0,48	3

Appendix 8: Example of output table

	Approach 1						Approach 2					
XXXXXX	Mean inventory	Serv2	ServIKEA	Weighted Serv2	Weighted ServIKEA	Mean cost	Mean inventory	Serv2	ServIKEA	Weighted Serv2	Weighted ServIKEA	Mean cost
Storenumber	units	%	%	%	%		units	%	%	%	%	
DC	13,79	35,9%	8,1%			13,79	56,60	67,7%	55,6%			56,6
STO1	0,30	96,2%	6,5%	11,4%	0,8%	10,61	18,57	97,6%	95,5%	11,6%	11,3%	24,9
STO2	7,10	76,6%	81,5%	1,3%	1,4%	16,16	8,62	91,1%	95,7%	1,5%	1,6%	12,1
STO3	2,43	30,2%	32,6%	4,6%	4,9%	244,38	15,19	95,0%	96,6%	14,4%	14,7%	32,3
STO4	3,33	39,4%	42,9%	3,7%	4,0%	131,92	12,86	94,1%	94,6%	8,8%	8,8%	25,4
STO5	4,23	49,0%	52,1%	3,0%	3,2%	74,84	10,97	96,3%	97,4%	5,8%	5,9%	16,1
STO6	5,05	43,8%	53,1%	3,6%	4,4%	111,30	16,29	89,5%	95,7%	7,4%	7,9%	36,1
STO7	5,38	62,2%	63,1%	2,4%	2,5%	38,93	9,11	94,1%	95,4%	3,7%	3,7%	14,4
STO8	5,18	56,0%	59,5%	3,2%	3,4%	63,16	10,01	95,5%	95,9%	5,5%	5,5%	16,0
STO9	7,23	82,5%	83,5%	1,5%	1,6%	14,73	8,42	95,6%	97,2%	1,8%	1,8%	10,3
STO10	4,34	44,2%	47,6%	4,4%	4,7%	131,11	13,74	93,5%	95,3%	9,3%	9,5%	28,5
STO11	5,23	57,2%	61,0%	2,9%	3,1%	55,45	10,75	93,6%	97,2%	4,8%	5,0%	18,3
STO12	4,19	47,7%	50,5%	3,0%	3,1%	78,11	10,89	96,0%	96,9%	5,9%	6,0%	16,5
STO13	6,49	76,9%	77,2%	1,5%	1,5%	16,63	8,03	97,2%	97,6%	1,9%	1,9%	9,3
STO14	5,68	67,8%	68,0%	1,8%	1,8%	25,00	8,80	95,1%	97,0%	2,5%	2,5%	11,7
STO15	5,99	69,9%	71,1%	2,0%	2,0%	25,81	8,67	95,5%	96,2%	2,8%	2,8%	11,6
STO16	4,58	55,5%	58,5%	2,5%	2,7%	50,95	9,87	95,2%	97,2%	4,3%	4,4%	14,9
STO17	5,76	63,6%	66,9%	1,8%	1,9%	29,27	8,73	94,6%	97,5%	2,7%	2,8%	12,3

A	B	C	D	E	F	H	I	J	K	L	M	N	O	P	Q	R
145,6%	168,9%	21,8%	129,69%	310,50%	155,58%	11,15%	-764,83%	-68%	40,1%	49,2%	-40%	0%	36%	68%	7,6%	-1,5%

See Appendix 6 for a list of the abbreviations used.

Appendix 9: Compilation results, daily measuring

Article number	Service requirement	Service class	Daily vs Weekly	Weekly vs serv2	Daily vs Serv2
xxxxxx	99%	High	0,43%	1,45%	1,62%
xxxxxx	90%	Low	0,30%	1,80%	1,81%
xxxxxx	90%	Low	0,48%	6,68%	6,59%
xxxxxx	99%	High	0,47%	1,57%	1,76%
xxxxxx	95%	Middle	0,52%	2,05%	1,95%
xxxxxx	99%	High	0,37%	2,16%	2,13%
xxxxxx	99%	High	0,18%	2,26%	2,22%
xxxxxx	90%	Low	0,52%	4,11%	3,94%
xxxxxx	95%	Middle	0,47%	2,99%	2,83%
xxxxxx	95%	Middle	0,49%	2,03%	2,15%