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Inventory control at Swedwood group

- A study mapping the current inventory control models and suggesting on a model that is to be the company standard

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Preface

This master thesis was written during late 2008 and early 2009. The thesis is the last step before obtaining a Master's degree in mechanical engineering with a major in logistics. The study was written in collaboration with Swedwood International AB within the Swedwood Group.

I would like to thank Swedwood for giving me the opportunity to write my master thesis in collaboration with them and for the warm welcome they gave me. Special thanks are sent to Peter Ac and the rest of the Supply Chain Development group. Their help in providing me with contacts within Swedwood and IKEA and their willingness to answer questions at anytime has been most helpful. I would also like to thank everyone at Swedwood's production units who have helped me with guided tours in the factories, providing statistics, taking time to being interviewed, and their interest for my work.

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Abstract

Swedwood is one of IKEA's key suppliers and they are also a member of the IKEA group. Presently Swedwood is running a project called @-cap with the purpose of creating joint processes and ways of work for the Swedwood group. This thesis is a sub-project evaluating the current inventory control methods and models.

The methodology approach chosen was inductive combined with qualitative and quantitative methods. Primary data was gathered mostly via interviews. In order to sustain a high level of credibility many sources were used to verify background data. The theoretic framework was exclusively formed by research reports and literature, both of which having their origin from well established universities or organisations.

The inventory control at Swedwood is characterized by very large volumes. At the moment, these volumes are not controlled by a uniform classification model. To only use the IKEA service classes does not differentiate the products properly wherefore the use of double criterions ABC-classification with the criterions frequency and the IKEA service class is preferable.

The Swedwood setup of a time-phased order point system needs some refinement. The current setup would benefit from an elongated planning period with a step-by-step filling of DOs into the MPS. The inventory control system ought to be modified to account for undershoots since undershoots have a large impact on customer service.

The production cost must be kept as low as possible. In order to realise low production costs, production is based on forecasts. The quality of these forecasts is currently too uneven where it does not reflect on the actual need satisfyingly. The quality of forecasts has a substantial impact on production costs.

The safety stock policy used at Swedwood is somewhat crude and does not reflect enough on customer needs. The current safety stock policy needs to be changed gradually into more refined calculation models.

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1 Introduction

This chapter will provide the background for the master thesis and the problem analysis will be presented. The intention of the master thesis will be described under purpose. Target audience and the delimitations will furthermore be clarified. The chapter is finished with a short company presentation.

1.1 Background

Swedwood is a member of the industrial group within IKEA and is one of IKEA's main suppliers. The company encompasses all stages of the manufacturing process from raw materials to the finished product. Although not all production facilities encompass all stages. IKEA often use Swedwood as a benchmark against other suppliers. Traditionally much focus has been put on keeping the production units as efficient as possible. As a result, most of the production facilities are very large and highly specialized. The specialization is focused on efficiency in production and not the entire supply chain.

The organizational structure is decentralized, where units have self-developed processes, but purchasing and technical development are coordinated. Since Swedwood often is used as a benchmark against other suppliers it is very important that Swedwood is able to meet the requirements put by IKEA. Delivery security is one important criterion to fulfil and this is satisfied by keeping stocks of finished goods. To keep stocks of finished products is costly; too large stocks of finished goods will result in decreased profits and with too low stocks Swedwood risks not to fulfil the agreed service levels to its customers. By not having a company policy on inventory management it is hard for the top management to review if the production units have reasonable levels of stock or not.

Recently Swedwood has launched a project called @-Cap. The purpose of @-Cap is to document, to create processes, and ways to work that can be used by all production units. The @-cap project is a step in the process of centralizing the organisation. This is supposed to ease benchmarking, optimize management, and reduce costs. Not all units have yet been included in the @-cap project but the intention is that all will be.

1.2 Problem analysis

Today each unit has its own model for warehouse management, some of them work quite well while others could use some improvement. All stock keeping is made in a logistics center located in conjunction with the production facilities. The logistics center is partly responsible for the Order-Fulfillment process which includes five sub-processes. In general, stocks are high due to fear of not being able to satisfy customer needs. As a measure to stay competitive Swedwood has decided to review inventory management used in the production facilities. The introduction of a common company policy on inventory management has a great potential to reduce capital deployment in finished goods stock.

In accordance with the description above this master thesis will focus on the following questions:

How well do the existing models for inventory management support the service levels required by the customers?

What parameters are to be considered when choosing on a model?

What model should Swedwood use for inventory management, could an existing one be used or shall a completely new one be developed?

1.3 Purpose

The purpose of this master thesis is to map the current inventory management models. The purpose is also to suggest on a model for inventory management that could be used in practice in the production facilities. The model should preferably be simple and easy to use and if possible be utilizable in all production facilities within the delimitations. If no existing models could be applied to the Swedwood production facilities an attempt to create a new one will be made. The model should preferably enable stock reduction without jeopardizing the service levels.

1.4 Delimitations and focus

The model that this master thesis will suggest upon will be valid for those production units that deliver directly to customers, i.e. IKEA; production units that are supplying other Swedwood production units will be excluded. All models requiring profound mathematical skills that can not easily be handled by a computer will not be discussed since these models will be hard to use in practice. The model does not intend to cover inventory management for all products; it will focus on managing finished goods inventory. The model will only cover generic products that do not vary in demand during the year. Examples of products and forecasts presented in the master thesis are mostly based on best-practice examples. Much of the focus is put on the models for safety stock and what parameters having the biggest influence on safety stock levels.

1.5 Target audience

This master thesis is aimed at logisticians working with warehouse management and process development at Swedwood International AB, personnel at IKEA, engineering students with a major in logistics, and teachers and professors at Lund University, Faculty of Engineering, within the Department of Industrial Management and Logistics. This group is believed to have substantial knowledge when it comes to logistics and logistical terms, hence this report will not explain concepts and words that this group ought to know.

1.6 Assignment specification set by Swedwood

The assignment set by Swedwood is twofold; map the existing inventory management models for a selection of representative production facilities and suggest one model that can be used as the standard model for inventory management. One of the demands set by Swedwood is that the model must be able to work in practice. The part of the model covering safety stocks does not have to be applicable to the existing ERP-system, i.e. M3 (Movex). The best theoretic solution that can be applied in practice is to be found.

1.7 The Swedwood Group

Swedwood was founded in 1991 as subsidiary to IKEA. The reason IKEA founded Swedwood was due to the political and economic situation in Eastern Europe at the time. Eastern European manufactures constituted a vital share of IKEA's supplier base. Swedwood was founded as a measure to secure supplier capacity. The initial task for Swedwood was to aid IKEA suppliers in their privatisation process when required.

Today Swedwood has more than 40 production units and offices in twelve different countries. The majority of production is based in Eastern Europe but there are also production units in Sweden, Germany, Portugal, and the USA. In 2007 Swedwood had almost 15 000 employees who manufactured nearly 80 000 000 units of furniture. The total value of production year 2007 was approximately 1200 MEUR (Million Euros). Swedwood is a quickly growing company with an approximate annual growth of 25% and production is doubled every three years.

Within the Swedwood group there is a strong emphasis on production efficiency. The aspiration for a high yield from the input material is supposed to reduce the cost and decrease the environmental impact. Production units are in general quite big in order to achieve economies of scale. Furthermore the production range for each production units is, if possible, concentrated to a limited number of products to avoid unnecessary setups.

Swedwood has four categories of products: solid wood, kitchen, board on frame and flatline. As the name solid wood suggest, products within this category are made out of solid wood. The kitchen area manufactures various fronts for kitchens and wardrobes. Board on frame products are sandwich constructions made of two boards with a honeycomb filling in between. Flatline manufactures flat furniture as kitchen cabinets and wardrobes out of veneered, printed or melamine faced boards. These categorise also form different sectors in which the company is divided in. These sectors all share some centralized functions.

2 Methodology

In this chapter the methodology and the methods used in the master thesis are presented. Procedures that were used to fulfil the purpose are described. The aspects of reliability and validity are discussed and how the master thesis has tried to obtain a high level of validity and reliability. The chapter is closed with a motivation for chosen the specific methodology and methods.

2.1 Research methodology

The first step when researching is reflecting on what the problem really consists of and how to approach it. Problems will be analyzed differently depending on their nature. There are four approaches to a problem and the approach is largely chosen based on the existing knowledge regarding characteristics of the problem. The four approaches are; exploratory studies, descriptive studies, explaining studies, and normative studies. Exploratory studies are used to get an image of the problem, in what situations it usually occurs, and the parameters that are important to take into consideration. Descriptive studies are used when the research is supposed to determine the properties of the object being studied. The purpose of an explaining approach is to respond to the question "Why?", it is often used when dealing with cause-effect problems. When the solution to a problem is supposed to result in an action plan, a normative approach is suitable.[1] This master thesis is best seen as mix of a normative study and descriptive study.

There are three major methodology approaches when researching; inductive approach, hypothetic-deductive approach, and abduction.[2]

Induction

When performing a study with an inductive approach, the starting-point is always a gathering of empirical content. Based upon the empirical data, general conclusions as well as theoretical conclusions are drawn. An inductive approach is often required when the research is of an explorative nature. Impartiality is important when gathering data, by emphasizing this subjectivity is not compromised.[3] In this master thesis an inductive approach was chosen.

Deduction

The hypothetic-deductive embraces the importance of the theoretical background and the hypothesis. This approach permits that hypothesis are drawn upon existing theories as long as rules and logic of the existing theories are applied. To be able to employ a deductive approach it is important to have substantial knowledge of the object that is being examined. The ideal is to test the hypothesis with experiments where parameters are varied systematically.[4]

Abduction

With abduction conclusions of causes to an observation are made. Unlike deduction where parameters can be varied, abduction intends to discover the causes without varying any of the

[1] Wallén, *Vetenskapsteori och forskningsmetodik* (1996) p45-47
[2] Ibid. p47-48
[3] Ibid. p47-48
[4] Ibid. P47-48

parameters.[5] Abduction can be seen as a mixture of induction and deduction since elements of both are used to solve the problem.[6]

2.2 Data gathering

The information used in this master thesis derives from many different sources. Examples of these are; interviews with personnel in concerned departments at Swedwood international AB, observations at various production sites, literature studies, and internal corporate documents. Before conducting the interviews, templates for questions were made as a preparatory action. The information gathered was used in the creation of the model for inventory management. The information used in this master thesis derives from five different production units and the management in Ängelholm.

The choice of methods for data gathering was chosen in consultation with the supervisor at Swedwood and the supervisor at LTH. The methods were considered suitable for the task and were thought to provide a knowledge-base sufficient to solve the problem. Another reason for choosing these methods was the limited time frame of in which the master thesis had to be completed. Questionnaires were excluded since their contribution would be of no significance. Case studies was also excluded as data gathering since observations at production sites was believed to provide the same information as a case study would, hence the case study would not contribute with any new information.

Primary data

Primary data is data that do not exist prior the study in question. Primary data is unique for the specific study and its purpose is to be used in the study. The data can be gathered in different ways some of the most common methods are; interviews, questionnaires, and case studies.[7] The primary data in this master thesis originates mostly from interviews.

Secondary data

In contrast to primary data, secondary data has been gathered prior to the study. The original purpose of the secondary data could in many cases be different than its purpose in current study. When secondary data is gathered it is important to review the source and the content critically. It has to be determined if the information is accurate; and if it is subjective or objective. Secondary data is often to be found in literature and in electronic format.[8] The secondary data, used in the empirical chapter, in this master thesis derives mostly from the company's ERP-system in form of statistics. Literature in inventory management is also a source of secondary data and is used to create the theoretic framework. Much of the statistics that was used to make the analysis was based on best practice examples.

2.2.1 Qualitative and Quantitative methods

Qualitative research can not be measured numerically. The qualitative method is often used when is specific subject, or incident, is to be examined thoroughly.[9] The qualitative method is suitable when the characteristics are researched or when problems are identified. The need for qualitative methods

[5] Wallén, *Vetenskapsteori och forskningsmetodik* (1996) p48
[6] Björklund et al, *Seminarieboken* (2003) p62-63
[7] Ibid. p68 and p74
[8] Ibid. p67 and p77
[9] Björklund et al, *Seminarieboken* (2003) p63

is great when interpretations in a theoretic context are made, when dealing with vague in diffuse problems, or when symbols are interpreted. When researching real-life situations qualitative methods can be of good use. In social studies the qualitative method is a popular approach.[10]

Quantitative research method is the opposite of the qualitative method; everything can be measured and valued numerically.[11] The quantitative method is most common in natural science research.[12] Examples of quantitative methods are; mathematical models, and questionnaires.[13] In this master thesis a combination of both methods are used; the qualitative method to get the background and the inputs, and the quantitative method to create the model for inventory management.

2.2.2 Literature studies

Literature studies are an efficient and economic way to gather much information within a short time. It is an easy way to get hold of the existing theories concerning the topic.[14] Literature studies are the main source of secondary data in this master thesis. The literature was used to produce the theoretic frame of reference as well as give the author a more extensive knowledge in inventory management. The literature that was utilized in this master thesis consists of books on inventory management and warehouse planning; and internal corporate documents and handbooks. Furthermore some literature regarding business systems software was read to give the author an insight of how such a system operates.

2.2.3 Interviews

There are three main types of interviews; standardized, semi-standardized, and none-standardized. In a standardized interview the questions are decided in advance and follow a strict questionnaire.[15] The semi-standardized interview resembles the standardized in many ways, however there is one important difference; the semi-standardized interview allows further discussion in questions that are found to be of a particular interest.[16] In contrast to the preceding two types of interview, the none-standardized interview does not follow a pre-constructed questionnaire. The questions are determined largely on the answers given by the respondent. [17]

Interviews can be either quantitative or qualitative; the objective with a qualitative interview is to identify unknown phenomenon, in reverse the quantitative interview aims to discover the distribution of pre-determined answers to a specific phenomenon.[18] The qualitative method has been used in this master thesis. The interviews that were carried out were both none-standardized and semi-standardized. The interviews with personnel at headquarters in Ängelholm and with IKEA personnel were all none-standardized while interviews with personnel at production sites were semi-standardized where the questions were sent in advance to the respondents. The questions from interviews at production sites are presented in *appendix 1*. The purposes of the interviews carried out at headquarters in Ängelholm were to establish the task that was to be solved and to provide the

[10] Wallén, *Vetenskapsteori och forskningsmetodik* (1996) p73-74
[11] Björklund et al, *Seminarieboken* (2003) p63
[12] Wallén, *Vetenskapsteori och forskningsmetodik* (1996) p73-74
[13] Björklund et al, *Seminarieboken* (2003) p63
[14] Ibid. P67
[15] Starrin et al, *Kvalitativa studier i teori och praktik* (1996) p53-55
[16] Björklund et al, *Seminarieboken* (2003) p68
[17] Starrin et al, *Kvalitativa studier i teori och praktik* (1996) p53-55
[18] Ibid. p54-56

background to the problem. The interviews carried out at the production sites were made to determine what models for inventory management that were used and how they were used. In all cases the interviews was followed up by additional e-mail conversations with complementary questions.

2.2.4 Observations

Three different sites were visited and the observations were made at these sites; all of them were made at production sites at Swedwood International AB. In conjunction with the observations complementary interviews were made. The management at the production sites were aware of the observations and were also informed in advance that the observation was to take place at their facility. The choice of which production site to visit was made in consultation with the management at headquarters in Ängelholm. The chosen sites were believed, by the management, to be the most representative for the production in general, although almost every production facility is unique. Impressions made at site were written down at location.

All observations were made to give the author an impression of how the inventory management is carried out in practice and if there were any contingent physical boundary conditions, i.e. pallet-sizes, that could affect the model for inventory management. All impressions are subjective and were not measured numerically.

2.3 Models

The purpose of models is to create a simplified image of a complex situation. A model is always based on a number of assumptions and rules that have to be fulfilled for the model to be of use, otherwise the model risk to generate incorrect results. Models can differ in type and will consequently produce dissimilar results. Examples of different models are; analogy models, normative models, and symbolic models. Analogy models are inspired by other fields of expertise than the current one. A normative model is describing an ideal situation of how something ought to be and does not have to be realisable. Several of the most common symbolic models are mathematical models where the parameters are the symbols and the model provides the link between them.[19] The models in this master thesis are symbolic and in some way normative.

There are certain criterions that models have to realize; the model is supposed to be systematic, i.e. no contradictions within the model may occur and logic has to be applied, the model is to be efficient, i.e. the result is expected, and the model must meet validity requirements.[20]

Models are one of the key components of this master thesis since the result will be presented in form of a model. The starting point was existing models and well established models that meet the demands for a model.

2.4 Method of analysis

Normally a problem can be analyzed with three different methods; statistical classification, modelling and simulation, and with a custom made purpose specific model. When data is analyzed through statistical classification, a correlations analysis is often carried out. The purpose of the analysis method is to determine the linkage between parameters and their interaction. Modelling and

[19] Wallén, *Vetenskapsteori och forskningsmetodik* (1996) p59-62
[20] Ibid. p59-62

simulation involves computer simulations. A computer is working the data by using special designed software. The custom made model can be used as preferred. Since it is custom made it can most likely be applied to specific study in question.[21] The method that was applied in this master thesis could be seen as a mixture between statistical classification and a custom made model. The focus of the analysis of the master thesis is on finding those parameters that have the greatest influence on service levels, and how they are to be optimized.

2.5 Reliability

High reliability implicates that the result will be the same if the study is repeated with the same execution. A prerequisite for high reliability is that the result ought to be the same regardless of who conducts the study, given the same methods are applied.[22] Reliability can also be defined as the quality and precision of the measurements. Reliability can be increased with more precise measuring instruments or with complementary questions at interviews.[23]

2.6 Validity

Validity can be defined as to what extent the measurements measure what they are supposed to measure.[24] A high level of validity is reached when the study does not have any systematic errors and when all essential parameter have been taken into consideration. If a model is used; and the predicted result aligns with the final result, the validity of the model is high.[25] Statistical correlations are often used to measure the validity by comparing the results with the accurate result. However, this can be hard to achieve when the research is of a qualitative kind. Validity is closely connected with reliability; however high reliability does not necessary generate high validity. On the other hand high validity usually generates high reliability.[26] Validity can be increased by utilizing different methods and by looking at the problem from different perspectives.[27] The relation between validity is shown in *figure 2.1* below.

Figure 2.1 illustrates the relation between validity and reliability. Source: Björklund et al, *Seminarieboken* (2003) p60

[21] Björklund et al, *Seminarieboken* (2003) p71-73
[22] Starrin et al, *Kvalitativa studier i teori och praktik* (1996) p209-210
[23] Björklund et al, *Seminarieboken* (2003) p59-60
[24] Starrin et al, *Kvalitativa studier i teori och praktik* (1996) p209-210
[25] Wallén, *Vetenskapsteori och forskningsmetodik* (1996) p61
[26] Starrin et al, *Kvalitativa studier i teori och praktik* (1996) p209-210
[27] Björklund et al, *Seminarieboken* (2003) p60

The first picture to the left in *figure 2.1* indicates that both validity and reliability is poor, the picture in the middle shows that reliability is good but the validity still is poor, and the picture to the right indicates that both validity and reliability is satisfying.

2.7 Methodology criticism and credibility of the master thesis

The questions in the problem analysis combined with the purpose of the study enforced the choice of an inductive approach. Another approach would therefore not have been possible with the demands from Swedwood. In conformity the type of study was also restricted to be a mix of normative and descriptive. If any other approach and research methodology would have been chosen the outcome might have been different. However, the other approaches and methodologies would have been hard to conduct within the given timeframe and may have been of limited value for Swedwood.

The selection of using both qualitative and quantitative methods was seen as necessary to be able to provide the reader with sufficient information. To only use one of these methods was believed to have issued a limited impression rather than a complete one.

The validity and reliability of the sources used to create the theoretical framework was believed to be high. Most sources are authored by researchers, academics or people with substantial knowledge within the concerned areas. Electronic sources have deliberately been excluded on behalf of research reports. Research reports were believed to be more reliable and to achieve a higher level of validity.

Much of the data was gathered via interviews and the answers provided were then interpreted by the author. All interpretations were subjective and therefore related with some uncertainties. To avoid misinterpretations and misunderstandings all information used from interviews has been revised by the people that were interview. To further validate the answers from interviews all information used was confirmed by two or more sources independently of each other. The content of this report has been shown for the management in Ängelholm, the personnel providing the information at the different production units, and to personnel at IKEA. All of them have approved the content.

To choose any other model for data gathering to provide the background and the none-quantitative information was seen as ineffective. Questionnaires were believed to be time consuming and would possibly not have been showed the same interest as interview would. With questionnaires there is also a risk of misinterpretation, especially when it is sent to different nationalities. Since the information derived from the interviews was confirmed from other sources it is believed to achieve a high level of reliability. The observations made at the different production sites did also confirm much of the information from the interviews. Indeed a case study would have had the same potential to provide the same information as an observation but in the authors opinion a visual impression was more valuable than a written description since it would be hard to fake. Another advantage with observations is that is primary data in contrast to a case study that is secondary data.

The information from interviews was believed to achieve a high level of validity. The validity was believed to be high because of the number of persons being interview and the number of questions at each interview. Furthermore the reliability was also enhanced by the fact that all of the interviewed personnel confirmed the data from previous interviews. The author has found no reason to mistrust the information given since it was provided from experts and the information provided contained both negative and positive aspects. The information derived from interviews was believed to present Swedwood and the methods used at the company in a representative way.

To collect the quantitative data in another way than directly from the Swedwood's ERP-system was not seen as possible. Some of the data might have been possible to retract from IKEA's ERP-system but to have done this would have been more troublesome than to do it directly from Swedwood. The information originating from the company ERP-system was considered to reach a high level of reliability and validity. This assumption was based upon the fact the company itself uses this information to manage the inventory levels and the production.

The choice of using best practice examples when analysing could have had a negative effect on the validity of this report. However, the author argues that the performance of these examples could be achieved by the majority of products since many products have the same features. It was believed that by including some of the less well performing products the result would not have been representing for the Swedwood inventory control principals. Moreover the choice of only including generic products without seasonal variations may have been negative for the validity. However, the vast majority of products that are produced by Swedwood are generic wherefore including products with seasonal variation could have been misguiding. It shall also be stressed that the author did not find any products with seasonal variations although it could not be concluded that no such products exist. The sheer size of the amount of statistical data ought to have a positive effect on validity. This was especially confirmed since all data made the same indications regardless of source.

The number of production facilities included in the study may have affected the outcome. However, these units were chosen since it was believed that their inventory control principals were representative for the Swedwood group. The author has not found any reasons or indications that the case should be any other. To include all production units would have provided a more complete description but would have been close impossible to carry out in practise.

The master thesis was largely influenced by the large production units within the Swedwood group. Surely these units had a large effect on the suggested models for inventory control. This in turn might have had a negative effect for the smaller production units. However, the author argues that the large production units had a bigger need for these models. Also it was believed that the large production units were more representative for the future Swedwood.

3 Theoretical Framework

In this chapter theories that will be used to analyse the empirical data are presented. The theories include a classification method, inventory control techniques, lot-sizing techniques, and safety stock calculation. All theories presented in this chapter are commonly used in practise while theories not used in practice have been excluded. Figures that have been redrawn from its original source are intended to capture the essential features of the original figure, not to be an exact replication. All pictures have been translated into English.

3.1 ABC-Classification

The ABC-classification is a classic technique in inventory control and it is based on research of Vilfredo Pareto. Pareto was studying how wealth was distributed among the people in Italy in the late nineteenth century. He discovered that income is concentrated to a small group of people, 20 percent of the population earned 80 percent of the total income. This distribution later proved to be valid for inventories as well where roughly 20 percent of the goods accounts for about 80 percent of total costs.[28]

Differentiated inventory control is an efficient way to prioritize where resources should be utilized. By using the ABC-classification it is possible to sort products after importance. Differentiated products can be managed differently. Some products can be controlled according to the *EOQ-model*[29] while others can use other inventory control methods. When classifying articles in an inventory one or more criterions are used. [30]

When items in an inventory are classified according to ABC-classification, or Pareto's law as it is also called, items are divided in three categories; A-category which is the most important one, B-category which is the second most important, and C-category which is the least important. In practice it is often so that A-items accounts for 15 percent of the total number of articles and 80 percent of the volume (if a volume value based criteria is used), B-items accounts for 30 percent of the total number of articles and 15 percent of the volume, and C-items accounts for 55 percent of all articles but just 5 percent of the total volume.[31] A typical ABC-classification, based on volume value, is illustrated in *figure 3.1* below.

[28] Orlickly, *Material requirements planning (1975)* p9
[29] Will be explained further later in this chapter under the "Lot sizing models"-heading
[30] Aronsson et al, *Modern logistik* (2004) p239-240
[31] Lumsden, *Logistikens grunder* (2006) p460

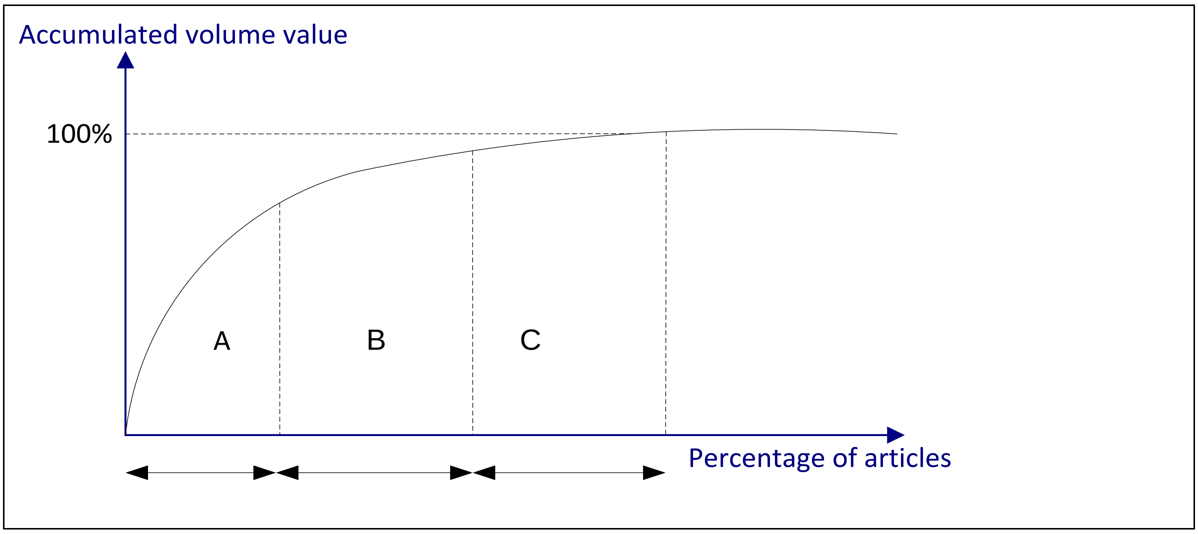

Figure 3.1 illustrates the appearance for a typical ABC-classification based on a single criterion. Source: Redraw Aronsson et al, *Modern logistik* (2004) p241

3.1.1 Single criteria ABC-classification

The most common usage of ABC-classification is based upon cost volume usage. The cost volume usage can be linked to the purchasing cost of the product, total capital deployed in storage, or total manufacturing margin. Obviously inventory is managed differently depending on category. For articles in the A-category it is suitable to keep a small safety stock and to replenish stocks continuously. Good contacts with suppliers in order to secure supply have to be embraced. For articles in the C-category however, it is more suitable with an easily administrated order point system. Safety stocks should be kept high and orders will be of bigger quantities than in the A-category.[32]

Another common way of conducting ABC-classification is to base it on frequency. When classifying items based on frequency the items that have the highest frequency will be placed in the A-category and so on. Differentiating products after frequency eases planning and forecasting, it also gives the opportunity to apply more elaborate models for inventory control and forecasting. Historical data of transactions is required to classify articles based on frequency. The transactions are later sorted in frequency charts and are then classified. [33]

3.1.2 Multiple criterions ABC-classification

There can be disadvantages to use ABC-classification with only one single criterion. For example there could be a dependency between an A-classed article and a C-classed article and if they are treated differently the consequence could be decreased service level. In this case an ABC-classification with multiple criterions would be appropriate.[34]

In many cases a single criterion ABC-classification is based upon financial parameters such as cost or capital deployment. However, there are many no cost criterions that have a significant importance

[32] Aronsson et al, *Modern logistik* (2004) p241-243
[33] Mattsson et al, *Produktionslogistik* (2003) p125-126
[34] Aronsson et al, *Modern logistik* (2004) p243-244

when managing inventories. Criterions of importance could be frequency, impact of running out of stock, available substitutes, and purchasing aspects.[35]

Classifying articles according to multiple criterions works, of course, in the same way as a single criteria classification. Normally a classification pursuant to cost volume usage is made and the articles are put into the categories, A, B, and C accordingly. When the first classification has taken place another one is made, often this classification is estimated and based on more implicit and intuitive values. The articles are distributed in three categories in the second classification, I, II, and III. The first and the second classification are then put together in a matrix as seen in *table 3.1* below.[36]

Criteria 1	Criteria 2		
	I	II	II
A	AA	AB	AC
B	BA	BB	BC
C	CA	CB	CC

Table 3.1 *Shows the classification of different articles with a classification according to a dual criterion ABC-classification.* Source: Redraw from Vollmann et al, *Manufacturing planning and control systems* (1988) p783

With the matrix the nine different categories are than reduced to three new classes; AA, BB, and CC. The categories can be managed in the same way as a normal single criterion ABC-classification.[37] The new classes are further illustrated in *table 3.2* below.

Criteria 1	Criteria 2		
	I	II	II
A	AA	AA	BB
B	AA	BB	CC
C	BB	CC	CC

Table 3.2 Shows the nine categories put together into three categories. Source: Redraw from Vollmann et al, Source: Redraw from *Manufacturing planning and control systems* (1988) p783

3.2 Inventory control

3.2.1 Order point system

The principal for an order point system is to place an order in time so material is received before the stock-on-hand reaches the safety stock level.[38] The system is based on continuous inspection of inventory and a comparison between the quantity in stock and a reference quantity, which is often called the reorder point (ROP). When the inventory position equals or drops below the reorder point a replenishment order is placed.[39] The replenishment order quantity is Q and the new inventory

[35] Vollmann et al, *Manufacturing planning and control systems* (1988) p781
[36] Ibid. p781-783
[37] Ibid. p783
[38] Bernard, *Integrated inventory management* (1999) p227
[39] Mattsson et al, *Produktionslogistik* (2003) p393

position will be ROP+Q, which is also the maximum committed level of inventory.[40] This is further illustrated in *figure 3.2*.

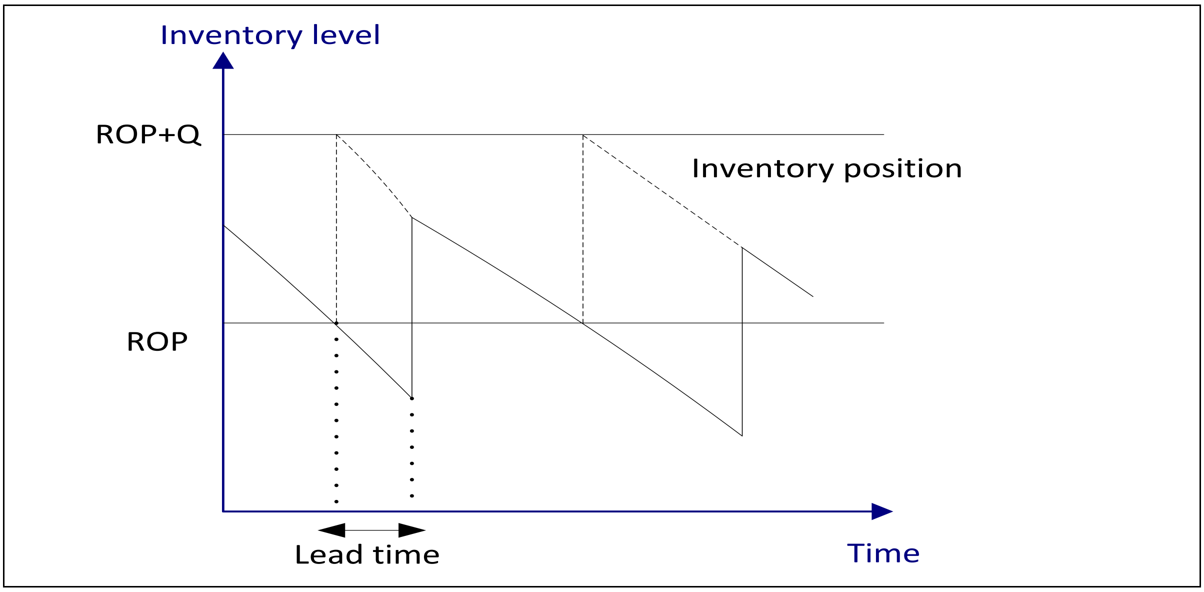

Figure 3.2 The figure illustrates a typical inventory with an order point system. Note that the inventory position does not equal to the physical inventory. Source: Redraw Axsäter, *Lagerstyrning* (1991) p42

The reorder point will be calculated as:

$$Reorder\ point = Forcasted\ daily\ usage \times Lead\ time\ days + Safety\ stock$$

It is not necessary to express forecasted usage and lead time in days, any time frame can be chosen.[41] The quantity Q that is being ordered can be of any value but it is appropriate the chose a quantity the equals the economic order quantity, EOQ. There is no manner to establish the time between orders in an order point system which could have entailments for suppliers; suppliers may need excess capacity in production in order to fulfil replenishment orders.[42]

To utilize an order point system historical data concerning previous consumption of items and quantity in stock is needed. If the system is used to manage generic products without any large variations in demand the ROP could be fixed. However, if the product has seasonal fluctuations the ROP has to be adjusted to be able to meet the demand otherwise the product risks stock outs or redundant inventory. [43]

The order point system is especially useful for finished goods inventory. Products suitable to be managed by an order point system are low value products and products with a level demand. [44]

3.2.2 Periodic ordering system

The periodic ordering system resembles the order point system to a certain extent. Unlike the order point system the periodic ordering system is not based on continuous inspection but on fixed

[40] Axsäter, *Lagerstyrning* (1991) p42
[41] Bernard, *Integrated inventory management* (1999) p228
[42] Lumsden, *Logistikens grunder* p329
[43] Mattsson et al, *Produktionslogistik* (2003) p395
[44] Ibid. p398-401

intervals between inspections.[45] The periodic ordering system does not have, unlike the order point system, a fixed reorder point. When the periodic inspection takes place, every article is reviewed and if necessary the article gets a replenishment order. The replenishment order is not adjusted to a pre-determined quantity, instead the order is exactly the size needed to get the inventory position to its maximum value.[46] An example of a periodic ordering system is illustrated in *figure 3.3.*

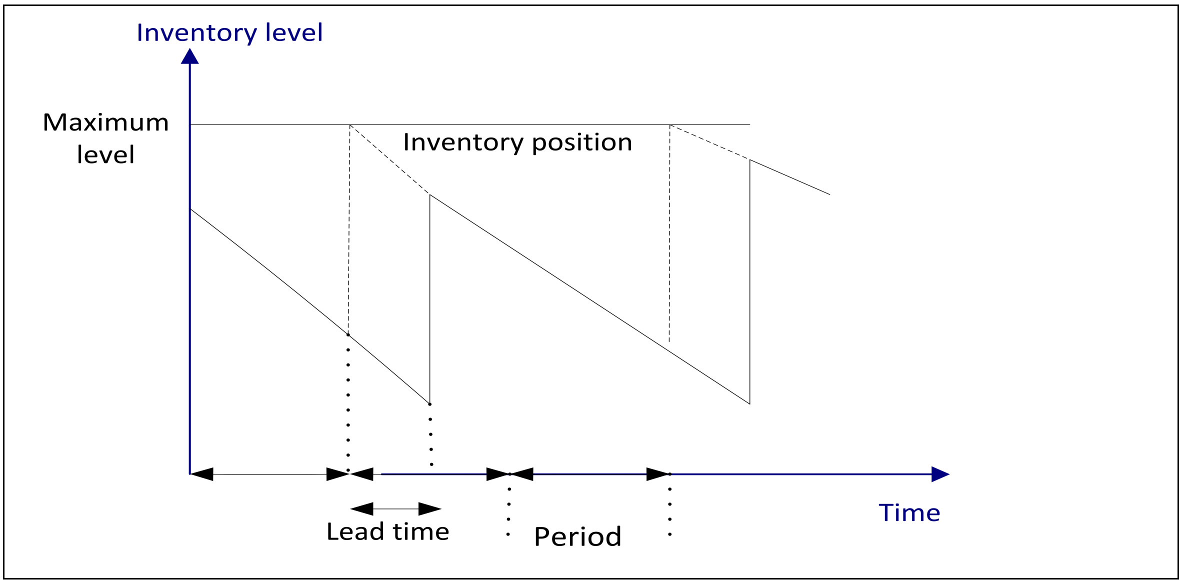

Figure 3.3 Illustrates a typical periodic order point system. Source: Redraw Axsäter, *Lagerstyrning* (1991) p43

One of the disadvantages with the periodic ordering system is that an article with an inventory position too low is not ordered directly, it is order at the next inspection. As a consequence the periodic ordering system tends to require larger safety stocks which contributes to a higher capital deployment. One of the big advantages though is the increased efficiency in administrative routines; it becomes possible to manage a large number article in a short time.[47]

There is one derivate form of the periodic ordering system where ordering take place when a Re-order point is reached, called the periodic review system. The periodic review system has a re-order point, ROP, and when the ROP is reached the replenishment order is placed. In the model the quantity being ordered is determined by the inventory position, the order is either the size sufficient to reach the maximum level of the inventory or a multiple of the EOQ.[48]

3.2.3 Time-phased order point system

One of the key features of a time-phased order point system is that goods are supposed to be received before stock outs and usage of the safety stock. [49] The system runs on the same principals as those of materials requirement planning, MRP. [50] Unlike the MRP the time-phased order point

[45] Axsäter, *Lagerstyrning* (1991) p43
[46] Mattsson et al, *Produktionslogistik* (2003) p396
[47] Ibid. p396
[48] Axsäter, *Lagerstyrning* (1991) p44
[49] Bernard, *Integrated inventory management* (1999) p230
[50] Vollmann et al, *Manufacturing planning and control systems* (1988) p802

system is utilized to control finished goods inventory and it does not control components used in the finished product like a MRP does.[51]

Unlike some other methods for inventory control the time-phased order point system comprises the lead time when calculating the placement for replenishment orders. There are two major characteristics for the system; firstly it is time-phasing, and secondly it always acknowledges product demand as forecasted demand. These characteristics make the time-phased order point system an eminent tool for managing finished goods inventory.[52]

The time-phased order point system includes forecasted demand in its calculation for the total demand. [53] The time-phased order point system is updated on regular basis; this could be done completely or partially. With the complete update the whole schedule is re-planned to fit new demands while the partial update only updates the inventory position.[54]

An example of a schedule for a time-phased order point system is illustrated in *example 3.1* below. The prerequisites are shown in *table 3.3*.

Lead time	Available inventory	Safety stock	OQ Technique	Unit of measure
5 weeks	100	40	200 fixed quantity	PCS

Table 3.3 the prerequisites for *example 3.1*.

[51] Axsäter, *Lagerstyrning* (1991) p120-121
[52] Orlickly, *Material requirements planning (1975)* p33-36
[53] Bernard, *Integrated inventory management* (1999) p230-231
[54] Axsäter, *Lagerstyrning* (1991) p120-121

		Period (week)					
		1	2	3	4	5	6
Independent demand		60	55	40	80	65	60
Gross requirements		60	55	40	80	65	60
Scheduled receipts		200					
Projected available	60	200	145	105	25	160	100
Net requirements						40	
Planned order receipts						200	
Planned order releases	200						

Example 3.1 illustrates a typical time-phased order point system. The example emanates from week zero. Source: Bernard, *Integrated inventory management* (1999)

Note that the time-phased order point system does not have to use pre-determined fixed order quantities as in *example 3.1*.

3.2.4 Two-Bin Technique

The two-bin technique is in essence a manual version of the order point system. With the technique each article or storage space is separated into two different physical parts. The first bin can be consumed without any need for action. The second bin is supposed to contain an amount that is sufficient to cover the demand during the lead-time for replenishment. The second bin also keeps a safety stock. When articles start to be consumed from the second bin it is time to place an order for replenishment.[55]

When the replenishment order is received each bin is filled to its intended quantity. At all time the bins stay separated from each other. The technique is mostly used for goods that are bought in bulk, stationary supplies or items purchased on a random basis.[56]

3.3 Lot sizing models

One of the most common and simple methods for determining lot-sizes is not really a model. The method decides the quantity that is to be ordered according to every single unique demand. Since the method only order products when there is a demand for it there will be no inventory and hence no capital deployment. The method is mostly used when products are customer specific, very expensive, or ordered Just-In-Time.[57]

[55] Bernard, *Integrated inventory management* (1999) p233
[56] Ibid. p233
[57] Mattsson et al, *Produktionslogistik* (2003) p450

3.3.1 EOQ-model

The EOQ-model, also called the Wilson equation, is the most common model for deciding lot-sizes; EOQ is an abbreviation of Economic Order Quantity. The purpose of the EOQ-model is to optimize the cost related to placing a specific order and the cost for carrying inventory; the relation between the costs and the EOQ is illustrated in *figure 3.4* below. The basic model is based on the following assumptions; the demand during a cycle is known, the lead time for stock replenishment is constant and identified, the stock is replenished with the whole quantity at a specific moment, the ordering cost is fixed and not depending on the quantity, the inventory carrying cost is fixed and refurdless of the quantity, and the price is constantly fixed.[58]

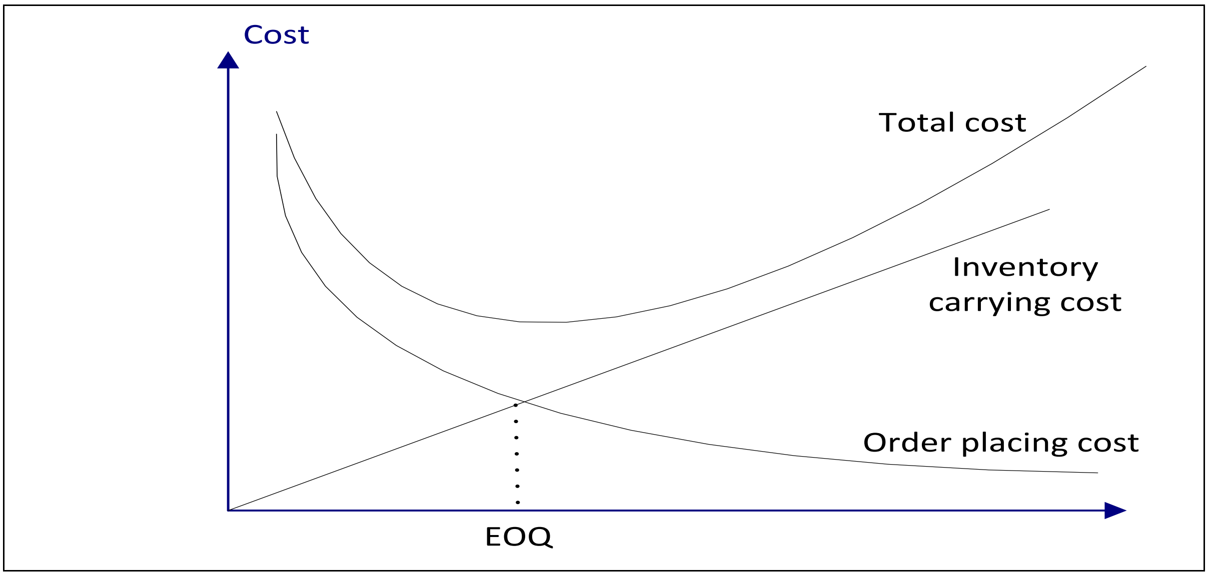

Figure 3.4 *Illustrates the relation between the cost for carrying inventory, the cost for placing an order, and the total cost.* Source: Redraw Aronsson et al, *Modern logistic* (2004) p221

The EOQ is determined by the Equation, *Eq. 3.2:*

$$EOQ = \sqrt{\frac{2 \times C_P \times A}{C_H}}$$

$Where:$
$C_P = The\ cost\ for\ one\ order$
$A = The\ annual\ demand$
$C_H = The\ inventory\ cost\ per\ item\ per\ year$

(Eq. 3.2)

The EOQ-equation is derived from the total cost equation. The total cost equation is differentiated with respect to the determinative parameter Q. The calculated EOQ is the lot-size to be produced or order within each order cycle.[59]

One of the advantages with the EOQ-model is that the model is not largely affected if incorrect values of parameters are used. As can be seen in *figure 3.4* above, the total cost curve is quite flat

[58] Mattsson et al, *Produktionslogistik* (2003) p452
[59] Vollmann et al, *Manufacturing planning and control systems* (1988) p727-728

hence a rough estimated parameter will not be devastating for the end result. If for instance a parameter is doubled it will only increase the total costs with 6 percent.[60]

The EOQ can also be expressed as the economic time between order; TBO. The TBO is defined in *Eq. 3.3*:

$$TBO = {}^{EOQ}/_{W}$$

$Where$:
$W = The\ weekly\ average\ usage$[61]

(Eq. 3.3)

There are numerous variations of the original EOQ-model, the majority of which tries to eliminate some of the prerequisites for the formula. Two assumptions that often are incorrect are the ones concerning the production capacity and the fixed price.[62]

In many, if not all, cases the production rate is limited, fortunately there is a model that acknowledges the importance of this parameter and has taken it into consideration in the formula. With a limited production rate the stocks will be replenished gradually. The modified EOQ-equation, *Eq. 3.4,* will be as following:

$$EOQ\ = \sqrt{\frac{2 \times A \times C_P \times \left({}^{P-A}/_{P}\right)}{C_H}}$$

$Where$:
$P = The\ production\ rate$

(Eq. 3.4)

If the production capacity is more than ten times the annual demand the standard EOQ-model can be used.[63]

The assumption of a fixed price regardless of the quantity is often incorrect. Suppliers will habitually offer a discount if a larger quantity is purchased. Of course larger quantities mean increased costs for carrying inventory. However this increase in costs has to be compared to the savings made with the discount. In the case of discount a trade-off between the discount and the EOQ have to be made and the choice ought to be based on total cost.[64]

3.3.2 Silver-Meal

The Silver-Meal algorithm is a simple heuristic method for determining lot-sizes. The method is approximate and suitable when demand is shifting. The Silver-Meal algorithm operates sequentially when deciding on lot-sizes and when they are to take place. [65] Unlike the EOQ-model the Silver-Meal method is dynamic and lot-sizes are not fixed to a pre-determined quantity. The basic principal of the algorithm is to balance the inventory carrying costs against the cost for placing an order. The optimal

[60] Lumsden, *Logistikens grunder* (2006) p347-350
[61] Vollmann et al, *Manufacturing planning and control systems* (1988) p728
[62] Mattsson et al, *Produktionslogistik* (2003) p457
[63] Ibid. p459-460
[64] Vollmann et al, *Manufacturing planning and control systems* (1988) p728-729
[65] Axsäter, *Lagerstyrning* (1991) p58

cost is found when the cost for inventory carrying equals the cost for placing an order.[66] When using the Silver-Meal algorithm a low total cost will be achieved although it is not necessarily the lowest.[67]

The Silver-Meal algorithm determines how large an order should be by comparing the cost for the actual period with the cost for the actual- and the following period. If the cost for two periods is lower than the cost for one period the lot-size ordered have to cover two periods consumption. The cost for two periods is than compared to the cost for three periods. This comparison continues as long as the cost keeps decreasing, when the cost increases it is time to place a new order.[68] The algorithm, *Eq. 3.5,* can be expressed as:

$$\frac{A + h\sum_{j=2}^{k}(j-1)\,d_j}{k} \leq \frac{A + h\sum_{j=2}^{k-1}(j-1)d_j}{k-1}; 2 \leq k \leq n$$

$Where:$
$A = The\ cost\ for\ one\ order$
$h = The\ inventory\ carrying\ cost\ per\ unit$
$d_j = The\ demand\ in\ period\ j$
$n = The\ number\ of\ periods\ included\ in\ the\ replenishment$

(Eq. 3.5)

The Equation can also be expressed as *Eq. 3.6:*

$$\frac{A + h\sum_{j=2}^{n+1}(j-1)\,d_j}{n+1} > \frac{A + h\sum_{j=2}^{n}(j-1)d_j}{n}$$

(Eq. 3.6)

The second equation, *Eq. 3.6*, is more common. [69]

3.3.3 Estimated order quantity

The method of estimated order quantity is emanates from intuition and experience. The estimation is often made by a manager or experienced employee. Estimations can be made either each time a need arises with different quantities, or one time for many periods. A number of parameters normally affect the estimated order quantity; future demand, product value, the risk of obsolescence products, the amount of resources required, and the administrative workload are some of them. Estimated order quantity is almost always out performed by the EOQ-model. The method could, however, be used when the enterprise is lacking an ERP-system. [70]

3.4 Safety stock

All inventories are associated to some extent with uncertainty and therefore safety stocks exist. The uncertainty could involve parameters such as future demand, suppliers' delivery ability, and the physical inventory. The uncertainty can be divided into two categories; uncertainty concerning quantity and uncertainty concerning time. There are two methods of dimensioning safety stocks; manually and based on calculations.[71]

[66] Mattsson et al, *Produktionslogistik* (2003) p465
[67] Aronsson et al, *Modern logistik* (2004) p228-229
[68] Axsäter, *Lagerstyrning* (1991) p58-59
[69] Ibid. p58-59
[70] Mattsson et al, *Produktionslogistik* (2003) p451
[71] Ibid. (2003) p473

3.4.1 Service levels

There are many applicable measurements to evaluate service; however the two most common definitions of service levels are Serv1 and Serv2.[72]

The Serv1 service level measurement is defined as the probability of not running out of stock during an inventory cycle. The Serv1 is popular to use among enterprises, one of the reasons is because of the ease in which calculations are carried out. [73] One of the advantages of Serv1 is that it is reckoned to reflect customers' view of delivery reliability where delivery reliability is based on the number of times shortages occur rather than the quantity of the shortage. The Serv1 measurement has one not insignificant disadvantage though; it does not account the number of stock replenishments. The consequence is that stock outs will occur more often on products with a high rate of turn-over.[74]

The Serv2 service level measurement is defined as the proportion of the demand that can be delivered directly from the inventory. The Serv2 measurement is based on the annual demand and hence the measure tends to be more precise.[75] In contrast to the Serv1 measurement the Serv2 measurement accounts for the number of stock replenishments. As an effect estimations can be made on how big the shortage will be if a stock out occur. The downside with the Serv2 measurement is that calculations are less simple than the ones for Serv1.[76]

When Serv1 and Serv2 are used as parameters in the safety stock calculation the result between the two measurements will differ greatly even if the same service level is chosen. This will in turn affect delivery ability towards customers.[77]

If Serv1 or Serv2 are used as dimensioning parameters for safety stock calculation, the importance of customer demand structure has to be acknowledged. Large order quantities will reduce service levels; the impact is most obvious with the Serv1 measurement.[78]

3.4.2 Demand distributions

If service levels are to be utilized as dimensioning parameters for safety stocks it is necessary to beware of how the demand varies during the lead time.[79] When the demand is high the normal distribution is often applied. [80]

With normal distribution, the forecast is supposed to represent the average usage rate. The normal distribution is symmetric, i.e. there is an equal amount of deviations on each side of the arithmetic average.[81] The distribution is denoted $N(\mu,\sigma)$; where μ is the arithmetic average, and σ is the standard deviation. The values of μ and σ are determined by demand statistics and the parameters are expressed per period. Normally the standard deviation is affected by both variations in lead time

[72] Axsäter, *Lagerstyrning* (1991) p68
[73] Ibid. p68
[74] Mattsson, *Användning av cykelservice för säkerhetslagerberäkning* p2-3
[75] Axsäter, *Lagerstyrning* (1991) p68
[76] Mattsson, *Användning av cykelservice för säkerhetslagerberäkning* p3
[77] Ibid. p25
[78] Ibid. p18 and p25
[79] Mattsson et al, *Produktionslogistik* (2003) p474
[80] Axsäter, *Lagerstyrning* (1991) p65
[81] Bernard, *Integrated inventory management* (1999) p353

and variations in demand. One of the advantages of the normal distribution is that it is easy to use.[82] As a general rule, normal distribution can be applied when arithmetic mean of the demand equals or is greater than two standard deviations.[83] The complete equation, *Eq. 3.7*, of the normal distribution is illustrated below.[84]

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \times e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

(Eq. 3.7)

If the demand is low on the other hand the Poisson distribution could be more suitable. Unlike the normal distribution the Poisson distribution is a discrete distribution. The distribution is determined by its arithmetic average and the standard deviation equals to the square rot of the arithmetic average. The Poisson distribution is skewed around its arithmetic, which means that more values are to be found on one side than the other. [85] The Poisson distribution can be used when:

$$0{,}8 \times \sqrt{D} < \sigma < 1{,}2 \times \sqrt{D}$$

Where D is demand during lead time.[86]The complete equation, *Eq. 3.8*, of the Poisson distribution is illustrated below.[87]

$$p(k) = e^{-\mu} \times \frac{\mu^k}{k!}$$

(Eq. 3.8)

Both the Poisson and normal distributions have restrictions in their user interface. The normal distribution has trouble coping with short lead times and large fluctuations in demand, in these two cases the normal distribution risks including negative demand. An illustration of the phenomenon is shown in *figure 3.5*. The downside with the Poisson distribution on the other hand is that the variance equals the arithmetic average.[88]

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[82] Mattsson et al, *Produktionslogistik* (2003) p474-475
[83] Mattsson, *Efterfrågefördelning vid bestämning av beställningspunkter och säkerhetslager* (2003) p5
[84] Blom et al, *Sannolikhetsteori och statistikteori med tillämpningar* (2005) p62
[85] Mattsson et al, *Produktionslogistik* (2003) p475-476
[86] Axsäter, *Lagerstyrning* (1991) p67
[87] Blom et al, *Sannolikhetsteori och statistikteori med tillämpningar* (2005) p55
[88] Mattsson, *Efterfrågefördelningar för bestämning av säkerhetslager* (2007) p2

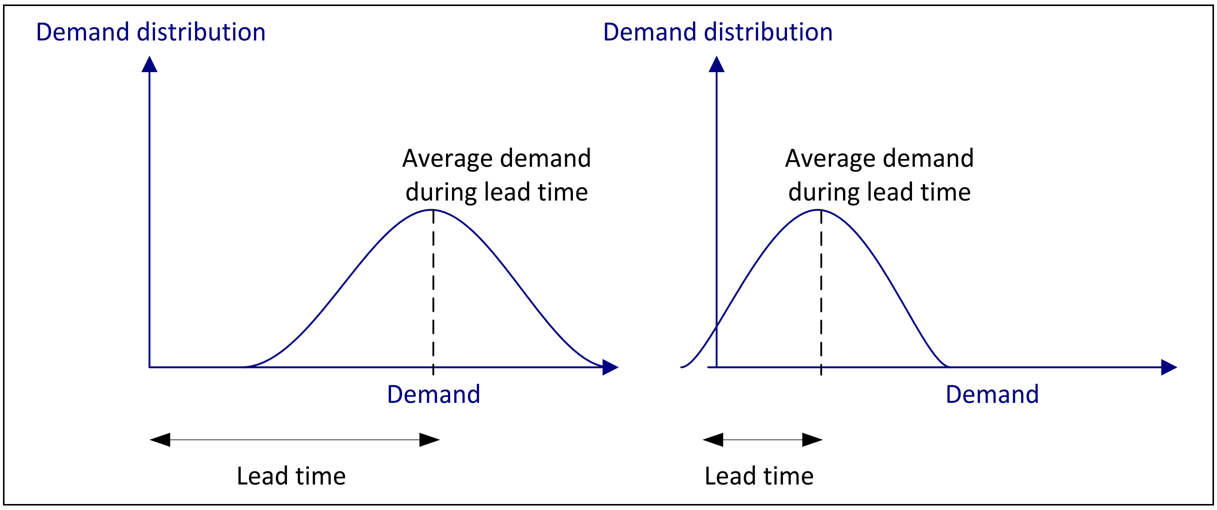

Figure 3.5 Illustrates the trouble with normal distribution with short lead times. Source: Redraw from Mattsson, (2007) *Materialstyrningsmodeller med hänsyn tagen till överdrag och olika efterfrågefördelningar* p4

An alternative distribution in the case of large variations or short lead times could be the gamma distribution. The gamma distribution does only comprise positive value and it is not symmetric. One of the characteristics of the gamma distribution is that it copes with large fluctuations in demand quite well. Another feature of the gamma distribution is its changeability; it has the properties of both the Poisson and normal distribution without any of the drawbacks.[89] The complete equation, *Eq. 3.9*, of the gamma distribution is illustrated below.[90]

$$f(x) = \frac{\lambda^p}{\Gamma(p)} \times x^{p-1} e^{-\lambda x} \,;\, x \geq 0;\ \lambda > 0; p > 0$$

where

$$\Gamma(p) = \int_0^\infty x^{p-1}\, e^{-x}\, dx$$

(Eq. 3.9)

The arithmetic average is expressed as; $\mu = \frac{p}{\lambda}$, and the standard deviation is expressed as; $\sigma = \sqrt{p/_{\lambda^2}}$.[91]

All of the distributions above are tied to follow the mathematic and statistic relations which can be a bite difficult. It is also hard to determine to what extent the distributions describe the actual demand. If the standardized mathematic distributions are found to be inappropriate for whatever reasons an alternative could be an empirically generated distribution based upon existing historic demand. In order to use this distribution the assumption that the historic demand will represent future demand has to be valid. The empirically generated distribution tends to handle variations in demand well if the lead time is short.[92]

[89] Mattsson, *Efterfrågefördelningar för bestämning av säkerhetslager* (2007) p2 and p10
[90] Blom et al, *Sannolikhetsteori och statistikteori med tillämpningar* (2005) p64
[91] Mattsson, *Efterfrågefördelningar för bestämning av säkerhetslager* (2007) p10
[92] Ibid. (2007) p2-3, p 5-8, and p29

3.4.2.1 The undershoot phenomenon

Many of the existing inventory control models used in manufacturing is based on the two assumptions; the demand during lead time follows a normal distribution, and the inventory position is reduced with one item at the time. In practice the inventory position is barely never reduced with only one item at time. The result in an order point system will be undershooting the reorder point more or less severe. The undershoot will in turn generate a higher rate of stock outs than most calculations take account. The stock outs will occur because most calculations are based on the assumption of reducing the inventory position of one item at a time. The difference between a theoretic model and an actual model illustrating the undershoot phenomenon is shown in *figure 3.6.*[93]

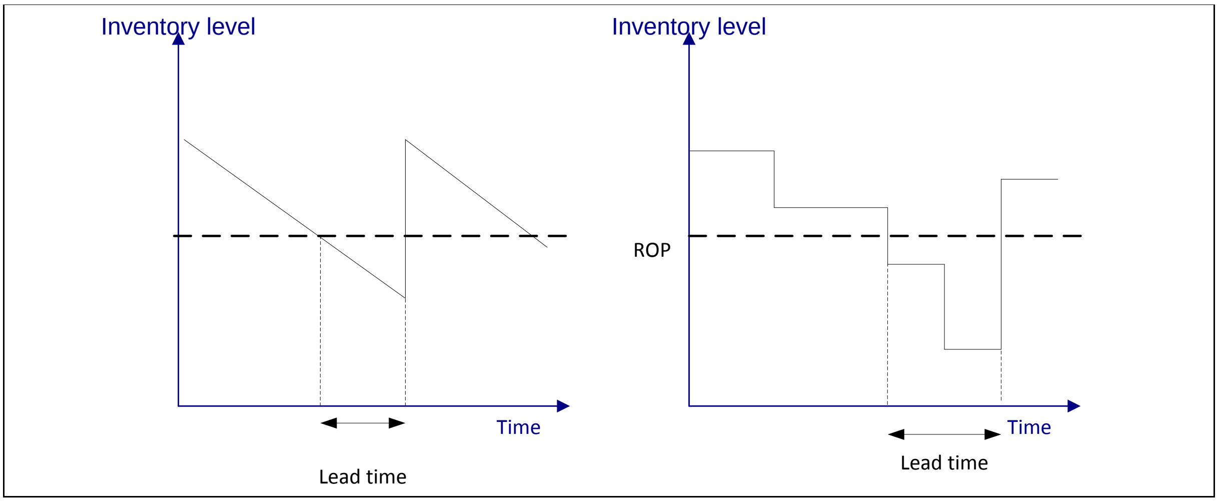

Figure 3.6 Illustrates the difference between a theoretic model on how the inventory position is changed and the actual case. Source: Redraw Mattsson, (2007) *Materialstyrningsmodeller med hänsyn tagen till överdrag och olika efterfrågefördelningar* p2

The impact of undershooting becomes larger with shorter lead times. To compensate for undershooting the service levels can be set higher than what is originally intended or a calculation of the undershot can be made. Increasing service levels does not solve the problem satisfying. The undershot is calculated, *Eq. 3.10*, as:

$$\mu_{Undershot} = \frac{\sigma^2 \times \mu^2}{2\mu} - \frac{1}{2}$$

(Eq. 3.10)

The undershoot is calculated per day. And the standard deviation, *Eq. 3.11,* for the undershoot will be:

$$\sigma_{Undershot} = \sqrt{\frac{\mu^2 + 3\sigma^2}{3} - \left[\frac{\mu^2 + \sigma^2}{2\mu}\right]^2 - \frac{1}{2}}$$

(Eq. 3.11)

93 Mattsson, *Materialstyrningsmodeller med hänsyn tagen till överdrag och olika efterfrågefördelningar (2007) p2*

The calculations are based on an order point system but can be applied to other models for inventory control as well.[94]

3.4.3 Statistical safety stock calculation models

The easiest of the statistical models for determining safety stock size is based on the Serv1 measurement. The equation, *Eq. 3.12*, is expressed as:

$$SS = k \times \sigma$$

$Where:$
$SS = Safety\ stock$
$k = Safety\ factor, specific\ for\ every\ service\ level$
$\sigma = The\ demand\ deviation\ during\ lead\ time$

(Eq. 3.12)

The value of the safety factor is further illustrated in *table 3.4* below.

Service level (in percent)	Safety factor
50,00	0,00
75,00	0,67
80,00	0,84
85,00	1,04
90,00	1,28
95,00	1,65
98,00	2,05
99,00	2,33
99,50	2,57
99,99	4,00

Table 3.4 Illustrates the value of the service factor k for different service levels. Source: Mattsson et al, *Produktionslogistik* (2003)

The demand deviation σ is calculated as *Eq. 3.13*:

$$\sigma = \sqrt{LT \times \sigma_D^2 + D^2 \times \sigma_{LT}^2}$$

$Where:$
$D = Demand\ per\ period$
$\sigma_D = The\ demand\ deviation\ per\ period$
$\sigma_{LT} = The\ lead\ time\ deviation$

(Eq. 3.13)

For small variations in lead time the terms $D \times \sigma_{LT}^2$ can be excluded. A more practical way of determining the standard deviation, σ, is to use the Mean Absolute Deviation, MAD. MAD is calculated, *Eq. 3.14* as: [95]

[94] Mattsson, *Materialstyrningsmodeller med hänsyn tagen till överdrag och olika efterfrågefördelningar (2007)* p2-3 and p17-19

$$MAD(t) = \alpha \times |P(t) - D(t)| + (1-\alpha) \times MAD(t-1);\ 0 < \alpha < 1$$

$Where$:
$t = The\ period$
$\alpha = The\ smoothing\ constant$
$P = The\ forecasted\ demand$
$D = The\ actual\ demand$

(Eq. 3.14)

The relation between MAD and σ is shown in equation, *Eq. 3.15,* below.

$$\sigma = \sqrt{\frac{\pi}{2}} \times MAD \approx 1{,}25MAD$$

(Eq. 3.15)

Note that MAD only can be used if the demand can be expressed as a normal distribution. The standard deviation based upon MAD is approximate which can make it inaccurate.[96] To obtain a value of the standard deviation that will support intended service levels, it is suitable to base the calculations on a large number of samples. The samples should not include demand with extreme peaks since the result will be redundant safety stock.[97]

The Serv2 measurement can also be used to calculate the size of the safety stock. The calculations are a bite more difficult. First the so called service-function has to be determined. The equation for the service-function, *Eq. 3.16*, is expressed as:

$$G(x) = \frac{(1 - Serv2) \times Q}{\sigma}$$

$Where$:
$Q = The\ average\ order\ quantity$

(Eq. 3.16)

The service-function is then used to determine the value of the safety factor, X. The safety factor can be determined via calculation according to normal distribution or the value can be read from a normal distributions table. An extraction from a table of normal distributions can be seen in below in *table 3.5*.

[95] Mattsson et al, *Produktionslogistik* (2003) p476-477
[96] Ibid. p381
[97] Mattsson, *Standardavvikelser för säkerhetslagerberäkning* (2007) p47-48

Service-function [G(x)]	Safety factor (X)
0,40	0
0,30	0,22
0,25	0,35
0,20	0,49
0,15	0,67
0,10	0,90
0,05	1,26
0,01	1,94
0,005	2,19
0,0015	2,59

Table 3.5 illustrates the safety factor for a given value of the service-function. Source: Mattsson et al, *Produktionslogistik* (2003)

The safety stock is then determined by a similar equation to the one of Serv1, the equation, *Eq. 3.17,* is expressed as:

$$SS = \sigma \times X$$

(Eq. 3.17)

Do note that the size of the safety stock will be different for the different methods even if the same service level is chosen. The both methods described above utilize the normal distribution to determining the safety stock size.[98][99]

Normal distribution in its unmodified appearance is not always suitable for safety stock calculation. In some cases the normal distribution with consideration taken to the undershot phenomenon will be more appropriate. To calculate safety stocks using normal distribution with undershoot, equation, *Eq. 3.18,* is used.

$$ROP = d \times lt + \mu_{undershoot} + k \times \sigma_{Day} \times \sqrt{lt + 1}$$

$Where$:
$d = The\ daily\ demand$
$lt = The\ lead\ time\ expressed\ in\ days$

(Eq. 3.18)

The safety stock is then determined by equation, *Eq. 3.19.*

$$SS = ROP - d \times lt - \mu_{Undershoot}$$

(Eq. 3.19)

All parameters not declared are the same as in previous examples and the safety stock is based on the Serv2 measurement. The safety stock calculated with normal distribution with consideration taken to undershoot will be more accurate and copes with fluctuations better.[100]

[98] Mattsson et al, *Produktionslogistik* (2003) p479-481
[99] Axsäter, *Lagerstyrning* (1991) p71-74

To be able to use gamma or empirically generated distributions for safety stock calculations a number of equations have to be utilized. First the service level has to be connected to the number of accepted shortages which is done by equation, *Eq. 3.20.*[101]

$$bkc = Q \times (1 - Serv2)$$

$Where$:
$bkc = The\ acceptable\ shortage\ per\ order\ cycle$

(Eq. 3.20)

The bkc factor is calculated in the same way for both distributions. When the bkc factor is determined the reorder point is determined. For the empirically generated distribution this is accomplished by equation, *Eq. 3.21*

$$E\ bkc(s) = \sum_{x/x \geq s} (x - s) \times p(x)$$

$Where$:
$E\ bkc(s) =$ The estimated shortage quantity per order cycle when reorder point equals
$x = The\ demand\ during\ lead\ time$
$s = The\ reorder\ point$
$p(x) = \ The\ probability\ that\ a\ certain\ demand\ during\ lead\ time\ will\ occur$

(Eq. 3.21)

The reorder point is then determined by equation, *Eq. 3.22.*

$$min|E\ bkc(s) - bkc|; for\ all\ s$$

(Eq. 3.22)

The reorder point with consideration taken to undershoot will then be, *Eq. 3.23:*

$$ROP = ROP(empirical) - d + \mu_{Undershoot}$$

(Eq. 3.23)

The safety stock is then calculated in the same way as for the case with normal distribution with consideration taken to undershoot.[102]

To determine the reorder point for the gamma distribution the E bkc(s) factor has to be calculated which it is by *Eq. 3.24*.

$$E\ bkc(s) = \ \mu \times \left\{1 - \left(\frac{\lambda^{p+1}}{\Gamma(p+1)} \times x^p e^{-\lambda x}\right)\right\} - \ s \times \left\{1 - \left(\frac{\lambda^p}{\Gamma(p)} \times x^{p-1} e^{-\lambda x}\right)\right\}$$

(Eq. 3.24)

The reorder point is then determined by the same equation as for the empirically generated distribution, *Eq. 3.22.* The reorder point will be, *Eq. 3.25:*

$$ROP = ROP(gamma) + \mu_{Undershoot}$$

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[100] Mattsson, *Materialstyrningsmodeller med hänsyn tagen till överdrag och olika efterfrågefördelningar* (2007) p22, p31-32 and p59-60
[101] Ibid. p35
[102] Mattsson, *Materialstyrningsmodeller med hänsyn tagen till överdrag och olika efterfrågefördelningar* (2007) p35-36

(Eq. 3.25)

Just like the case with empirically generated distribution the safety stock for gamma distribution is determined with the same equation, *Eq. 3.19*.[103]

3.4.4 Non statistical methods for determination of safety stocks

There are three techniques for designing safety stocks; statistical calculation of safety stock, fixed stock levels, and time period safety stock. The fixed safety stock remains at the same level during several periods and order cycles regardless of the rate in which items are ordered from the inventory. Fixed safety stock levels are appropriate to use when new items are to be phased-in or when old products are to be phased-out.[104]

Time period safety stock is calculated based on either forecasted demand or actual demand, in some cases a combination of both is used as well. The size of the safety stock is largely determined by the estimated usage rate during a cycle and the length of the period. Periods with a high usage rate will have a larger safety stock than a period with a low usage rate. [105]

3.5 Forecasts and forecasting techniques

For forecasts to be useful the demand should be fairly stable. Random independent demand can therefore not be forecasted. Forecasting methods can be split up into three categories; constant models, models with influences of trends, and models with influences of trends with a multiplication factor.106

3.5.1 Moving average

One common method used to forecast demand is the moving average. The moving average is a constant model that does not comprise the influence of seasonal variations or trends. The moving average is based on a number of previous demands. These previous demands are than used to calculate an average which in turn is used to make the forecast. The number of values that are to be included depends on how much the demand is believed to vary and how the large the fluctuations might be. The more values included in the forecast the less pendulous the forecast will be. The forecasted demand is calculated as expressed in equation, *Eq. 3.26*.[107]

$$X_{t+1} = [X_t + X_{t-1} + \cdots X_{t-(N+1)}]/N$$

$Where$:

$X_{t+1} = The\ forecast\ for\ period\ t + 1$

$X_t = The\ demand\ in\ period\ t$

$N = The\ number\ previous\ demand\ values\ included$

(Eq. 3.26)

Since it is a constant model the demand for the upcoming periods will be the same as for period t+1. [108]

[103] Mattsson, *Materialstyrningsmodeller med hänsyn tagen till överdrag och olika efterfrågefördelningar* (2007) P36-39

[104] Bernard, *Integrated inventory management* (1999) p342 and p368-370

[105] Ibid. p370-374

[106] Axsäter, *Lagerstyrning* (1991) p14-17

[107] Ibid. p18-19

[108] Ibid. p18-19

3.5.2 Exponential smoothing

In conformity with the moving average the exponential smoothing is also based on a constant model for demand. But unlike the moving average the exponential smoothing uses input from a previous forecast. The forecast used can be both calculated or an estimation of future demand. The forecasted demand is expressed as in equation, *Eq. 3.27.*[109]

$$A_t = (1 - \alpha)A_{t-1+}\alpha X_t$$

$Where$:
$A_t = The\ forecast\ for\ period\ t$
$\alpha = The\ smoothing\ constant$
$A_{t-1} = The\ Demand\ from\ one\ period\ back$
$X_t = The\ forecast\ for\ the\ current\ period$

(Eq.3.27)

The value of α is between 0 and 1. If the forecast is updated once a month, in practice the value of α is often set to be between 0.1 and 0.3. The bigger the value of α gets the more the responsive the calculation gets to changes in demand. Weekly updated forecasts on the other hand require a lower value of α to avoid unnecessary fluctuations in the forecast which might otherwise occur. The calculated method of exponential smoothing requires a start value to be initiated and a suitable value could be the average demand from the previous year.[110]

3.5.3 Forecast consumption

In short forecast consumption can be described as:

"The process of reducing forecast by consumer orders as they are received" [111]

The phenomenon of forecast consumption could further be explained as the difference between the forecasted demand and actual orders. Down below follows an illustrative example, *example 3.2*, of forecast consumption.[112]

Example 3.2

Consider a forecast for a four week period. The total forecasted demand for the four weeks is 40 pieces divided on 10 pieces per week. After the first week only 7 pieces were sold. If forecast consumption is applied, the forecast for the coming weeks may be altered. It could stay at 10 pieces per week without taking any consideration to the shortage in actual orders. It could also be adjusted so that week two would be set to 13 pieces while week three and four stay at 10. A third solution could be to distribute the shortage evenly over all three remaining periods leaving them at 11 pieces per week. [113]

There are different models for how to update forecasts according to forecast consumption. The differences lie in how the accumulated forecast deviation, compared actual orders, is being transferred into the following forecast periods. Another difference lies in when the accumulated

[109] Axsäter, *Lagerstyrning* (1991) p19
[110] Ibid. p20-21
[111] Cox et al, *Dictionary* (1998)
[112] Mattsson, *Prognosrullning för lagerstyrning och huvudplanering* (2004) p2
[113] Ibid. p2-3

forecast deviation is to be dropped. If the accumulated forecast deviation never where to be dropped the error is likely to gain in size.[114]

There are two cases to consider when working with forecast consumption; negative and positive autocorrelation. If the demand falls short of the forecast and is believed to be compensated by an increase the following week the autocorrelation is negative. In contrast is the positive autocorrelation where if one week as a high demand the following is probable to have a high demand as well. [115]

Forecast consumption is only effective in the case of a high degree of negative autocorrelation. For forecast consumption to be useful in this case the number of periods used in forecast consumption has to be short and the accumulated forecast deviation need to be distributed over these periods.[116]

[114] Mattsson, *Prognosrullning för lagerstyrning och huvudplanering* (2004) p4-6
[115] Ibid. p8
[116] Ibid. p12

4 Empirical data

This chapter contains empirical data that is to be in the analyzed. The chapter describes work routines and processes at Swedwood in general and it also has a short description of ordering and requirements from IKEA. The chapter is completed with examples of three representative production units, two Swedish ones and a Polish one. The data presented in this chapter originates from multiple sources and most data have more than one source.

4.1 Order fulfilment process

The order fulfilment process can in short be explained as the series of activities which take place in the logistics centre. At Swedwood the inventory is independent from the rest of the production. All inventories are called logistic centres and are not necessarily placed within the production facility. The logistics centre is solely responsible for the order fulfilment process which aims, as the name implies, to satisfy customer demand. The process consists of five sub-process and these are illustrated in *figure 4.1* below.

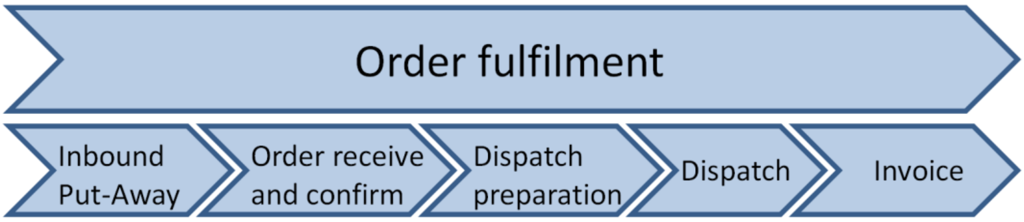

Figure 4.1 illustrates the order fulfilment process and its five sub-processes.

In the *inbound put-away* process goods is received at the logistics centre and a quality control is performed, if goods pass the control it is put stock. The *order receive and confirm* process performs a check against the shipping calendar and what is called Available To Promise, ATP, if the check verifies the possibility to ship the goods on the desired date the order is confirmed. The *dispatch preparation* creates deliveries and shipments, consolidate and build loads, allocate goods, order a hauler, and release the picking list. In the *dispatch* process goods are picked, trucks are loaded, delivery documents are printed, and the goods are dispatched. The invoice is sent after possibly being corrected in the *invoice* process.

The order fulfilment process is a general description of how work is carried out in the logistics centres and local varieties of the process exists. Logistics centres are very different in terms of the number of articles being store, it ranges from merely 10 articles up to over a 1000.

4.2 IKEA requirements and ordering

There are five different types of orders from IKEA. The first type is called B-orders and it accounts for 44 percent of the volume, financial year 2008, but the intention is to increase B-orders to a volume share of 55 percent by the year 2012. B-orders include direct deliveries to IKEA stores, orders to Customer Distribution Centres, CDC, transit orders, and orders to franchise stores. J-orders are another type of orders and it comprises orders to IKEA Distribution Centres, DC, which will further be denoted as regional warehouses. Additionally there are two types of fixed orders called F-orders and S-orders. The F-orders derives from the main trading office to which the supplier is connected. S-orders are orders for the US-market and dispatch-date is set together with suppliers. The last order type is called E-orders. E-orders are fixed as well but are periodic where the customer may place the order within a defined timeframe. All ordering for stores is decentralized, i.e. every store is solely responsible for its ordering. Ordering for regional warehouses is managed centrally and order sizes are depending on forecasts, stock on-hand, and orders in transit, i.e. order can vary in size from time to time and it is not set to a fixed quantity.

However, forecasts that are sent to suppliers are calculated centrally at IKEA headquarters. If the store orders goods from a regional warehouse the forecasted demand is derived from sales forecasts in stores and is then compared to the current safety stock, orders in transit, and the stock on-hand in the store. The same procedure is then repeated in the regional warehouse but instead of sales forecasts the input will be the demand from the stores. Stores ordering directly from suppliers send in their short-term forecasts to IKEA centrally. Finally the all forecasts are consolidated into one forecast. The forecast is reviewed so that it agrees with the commitment towards the supplier and the capacity then it is sent to the supplier. Forecasts are updated every week and cover a period of 24 weeks.

IKEA has four different service classes of their products. The service classes are set after the IKEA definition of service levels. IKEA measures service levels as follows: how many stores would like to keep the item in stock? This question is answered with yes or no. If 100 stores would like to keep the item in stock but only 99 had it the service level would be 99 percent. The measurement of service level is covering both supplier performance and IKEA's internal performance. Today IKEA does not track the source to the shortage if it is not a repeated problem.

IKEA also measures delivery security, it is a measurement of the timing of transports. For every day a transport is late the delivery security drops by a certain percentage depending on the lead time for the product. E.g. consider a product with an agreed-on lead time of ten days. The delivery security will drop with 10 percentage points for every day late the transport is. A product with an agreed-on lead time of five days will reduce delivery security with 20 percentage points for every day late and so on. Delivery security is based on the initially requested date from IKEA and the goods should be ready for dispatch on the requested day. For an order to have a delivery security of a 100 percent it has to be ready for dispatch on the requested date. Do note that the delivery security does not measure when the goods are received by IKEA but only when the goods are available for dispatch. For a delivery to be accounted it has to be complete, a part delivery is the same as a missed delivery.

The reports on supplier performance are sent to suppliers on a monthly basis. The reports contains a number of parameters covering fill-rate, price development, service level, and average action time just to mention some.

4.3 Classification

Swedwood does not have a company policy on classifying products. However there is a general description of an ABC-classification within the @-cap documentation. Since there is no company policy on classification each unit develop its own classification system and these must not necessarily comply with the classification described in @-cap.

The classification is not primarily used to control inventory levels. There is no classification within the production either, i.e. the Master Production Schedule, MPS, is not modelled to allocate a certain amount of time for a specific product-category. Both the safety stock levels and the MPS are moderated by the service classes set by IKEA, where products with high service class are prioritized. However, this rule is not applied in every production unit.

The classification is today used, in the logistics centre, to determine the physical placement for a specific product within the inventory. The classification is made by M3 and it is often based on frequency. M3 uses statistics from at least one year when making the classification. The classification aims to shorten distances for forklift drivers. This is done by placing products that have a high turn-over rate nearer to the loading-zone. Not all production units use this system for determining physical placement.

4.4 Inventory control

As described previously Swedwood uses logistics centres and these are managed separately in their ERP-system, M3, even though the production and the logistics centre uses the same system. Logistics centres are not linked together with other logistics centres but only with their respective production facility. However the new production units and logistics centres are all connected to the same version of M3 and is accessible at the headquarters in Ängelholm.

Almost all logistics centres use a time-phased order point system setup in M3. The setup in M3 does not necessarily conform to the theoretical time-phased order point system. The Swedwood setup includes both turn-over stock and safety stock. The setup of the time-phased order point system differs between different units. The difference lays in whether or not the forecasts are automatically corrected or not. Default setting is not to correct the forecast with M3. Forecasts are received from IKEA every week and the forecast consists of one master forecast covering the whole year and one more detailed forecast covering the coming weeks. The forecast for the entire year is quite accurate, in terms of total sales value, while forecasts for the following weeks tend to be somewhat imprecise. The short term forecast is often relatively good for a product group, i.e. the family name under in which several products are gathered as for instance the Lack range. For the product group the forecast is mostly within plus minus 10 percent of the ordered value. On article level however the forecasts are not very good, it is not uncommon that forecasts are more than plus minus 100 percent of the ordered value.

The forecast is sent directly to M3 in form of a Supply Plan Information-file, SPI, which contains all information about the demand for the upcoming weeks and also whether or not products are to change service class. The planner at each production unit has the possibility to correct forecasts manually which is done in many cases. The planner always uses the latest possible IKEA forecast when planning. The long term forecast does not comprise as explicit customer demand as the shorter one. The short term forecast expresses the actual demand for every week and it does not just provide an expected average for the upcoming weeks, e.g. if expected demand for the coming four weeks is 500 units the forecast is, in most cases, not expressed as a weekly demand of 125 but instead of a specific demand for every week.

The other part of the demand is actual customer orders. Customer orders are automatically checked against the ATP. The ATP checks the inventory position of the article being ordered, if the inventory position complies with the demand the order is released. If the stock-on hand is below the ordered quantity the ATP checks if there are any Distribution Orders, DO, from the production on its way in to the inventory, if there are and if the amount that is possible to allocate is sufficient the order is released. The order can have another delivery date than what initially was requested depending on when the DO is due to arrive to the logistics centre. If neither the inventory nor the DO is able to cover the demand for the order the logistics centre will release a DO to the production and cancel the order. Only J-orders are cancelled, B-orders are never cancelled but the dispatch date will be set later than requested. DOs are also released if forecasts indicate a demand that is greater than the inventory position. The cancellation of orders is done manually and not by M3. The cancelled order is checked according to the ATP the following day until it can be released. The delivery date will be set a couple of days later, for the cancelled order, to when the DO is due to arrive at the logistics centre. This setup never allows the inventory position to drop below zero. To cancel J-orders that will not be dispatched on requested date is a demand from IKEA. The interaction between the logistics centre, the customer, and the production unit is further illustrated in *figure 4.2*.

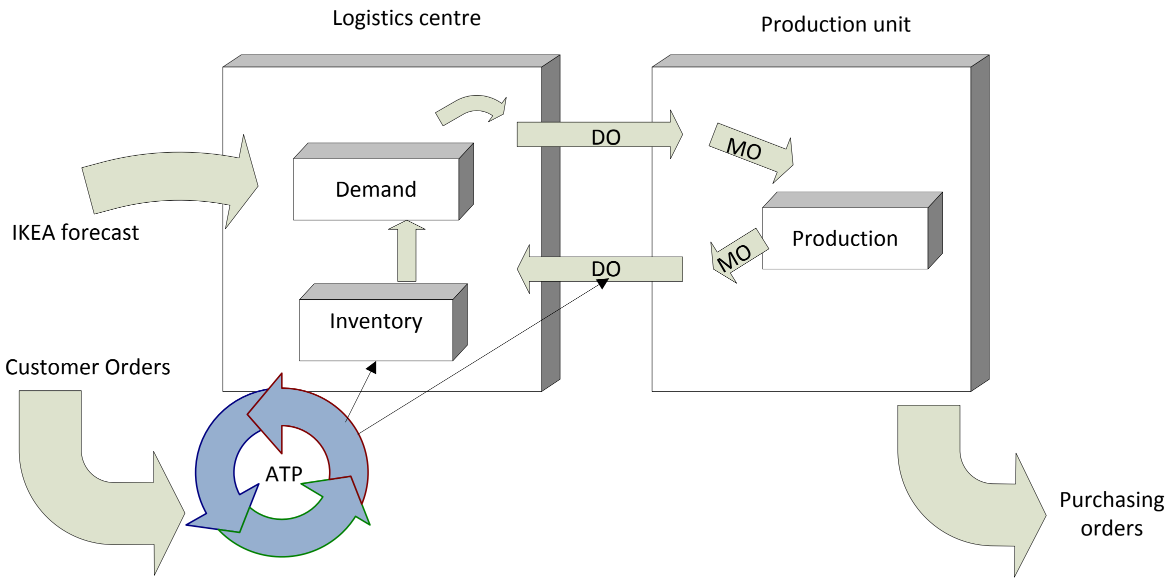

Figure 4.2 Illustrates the interaction between the logistics centre, the customers, and the production unit.

DOs received in the production unit will in turn generate Manufacturing Orders; MO. MOs are then planned into the MPS where the production is almost always planned to an utilisation of 100 percent. The actual capacity utilisation however is significantly lower than 100 percent. The MPS is set at a meeting between planners from the logistics centre and planners from production. After the meeting the MPS is programmed in M3. Sometimes the MPS is re-planned in the middle of a planning period due to raw materials shortages or failure in production equipment. The MO for some products may be set lower than the IKEA forecasted demand due to restricted production capacity. MOs will also trigger M3 to alert the purchasing department who in turn will create purchasing orders, PO, to acquire raw materials needed in production.

DOs from the logistics centre to the production are released once a week, on Fridays. The system will generate a DO proposal but the order is never released without the interaction of a planner. The purpose of only releasing DOs at Fridays is to consolidate demand, to level off the production, and decreases the risk of overproducing. DOs that are to be placed can only be placed two weeks from the current date. The first two weeks are already filled with other DOs that have been planned for more than two weeks. For the first booked week the sequence for the MOs is set. The second week is book but the DOs and MOs are not released until the following Friday. Also the sequence for MOs for the second booked week has not been determined. Supplementary DOs can only be placed within the two weeks in extraordinary cases. Not all products are produced every week, however most products have production intervals of 1-2 weeks. The possibility to place DOs is additionally explained in *figure 4.3*. However, DOs delivered from the production to the logistics centre can be delivered any day of the week since there is no fixed date for inbound deliveries to the logistics centre. All though inbound DOs have a latest delivery date.

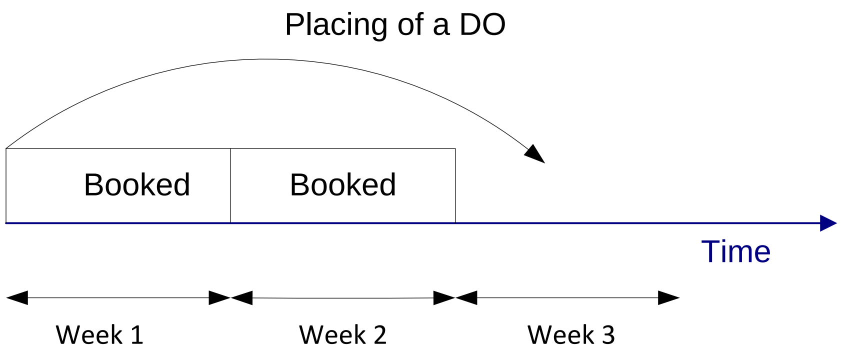

Figure 4.3 illustrates the time frame of a DO and how ordering take place

Normally the forecast is known prior to the customer order. In some cases though the order is place far in advance of requested delivery date. Since the Swedwood setup of a time-phased order point system accounts for both forecasts and customer orders special attention is drawn to customer orders that are placed far in advance and affects DOs. In the cases of early orders the Swedwood setup of a time-phased order point system determines the size of the demand, and indirectly the DOs, as the maximum quantity of the forecast and known customer orders. E.g. if the forecast for week three indicates a demand for 100 pieces and there are customer orders for 120 pieces the demand that triggers the DO will be of 120 pieces. In some logistics centres forecast consumption is practiced where the most common method is one-way negative autocorrelation, i.e. if the customer orders fall short of the forecast the demand for the following week is be believed to have an increased demand as an effect of the dip in demand the previous week.

4.4.1 Seasonality in inventory

All Swedwood production facilities close down every year for the annual summer holiday for three to four weeks. To be able to do so all Production units increase their production a couple of weeks in advance. During this time the Swedwood setup of a time-phased order point system accounts the demand for more weeks than normal. The inventory level is increased to compensate for the shut down. After the summer holiday the inventory levels are generally low. The summer holiday normally takes place in July-August.

4.5 Demand structure

The Logistics centres are supplying both regional warehouses and IKEA stores with products. Each logistics centre has a specific market to supply with goods. What characterizes the demand from both regional warehouses and IKEA stores is a vast increase in volume each year. The combined demand from regional warehouses and IKEA stores increases with approximately 10-20 percent per year and has done for a long time.

The single most important factor affecting the demand is the annual release of the IKEA-catalogue. The catalogue works as an enormous boost on the demand. The catalogue is released in August or September depending on country. Just after the catalogue release is the toughest time during the year for the production units since stock levels are low, due to the summer holiday, and the demand is increasing.

Orders from stores generally accounts for more orders than the ones from regional warehouses. Orders to stores are often of a small quantity since stores only keep a little amount of goods in stock. The frequency of orders is quite high and the demand is relatively stable during the year. The IKEA stores are controlling their inventories according to the same principals as Swedwood logistics centres, i.e. a time-phased order point system. In contrast to the stores the regional warehouse places its orders more seldom. The quantity ordered at each time is usually very large. It is not uncommon for an order from a regional warehouse to be more than a hundred times the size of an order from a store. Unlike the stores the regional warehouses do not use a time-phased order point system. The regional warehouses use a system based on coverage time. During financial year 2008 the average time between orders for regional warehouses was in the extreme case up to 2-3 months.

Even though the regional warehouses place a lot less orders than the stores the volume acquired accounts for more than 50 percent of the total volume. The impact regional warehouses' orders have on stock sizes is immense. The demand for a typical generic product, ordered by both regional warehouses and stores, during a period of 6 months is illustrated in *chart 4.1.*

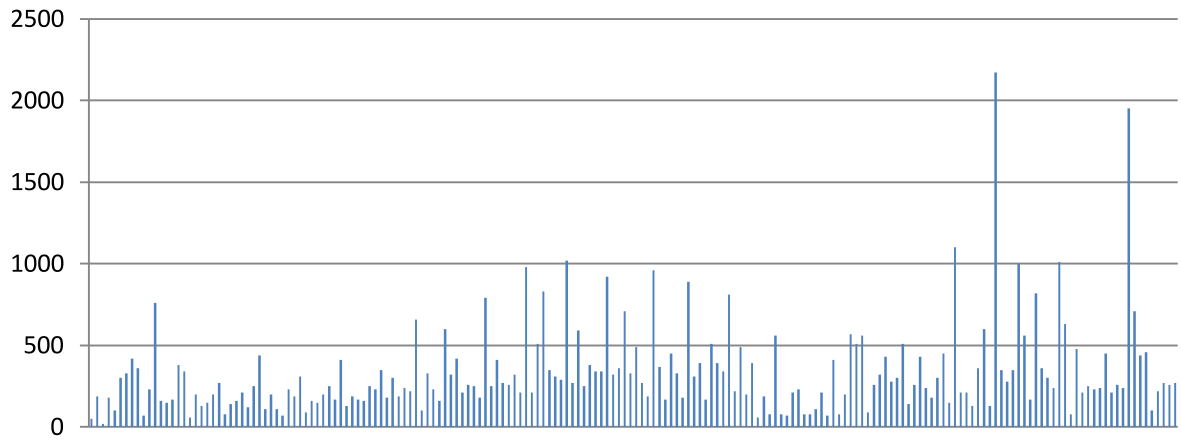

Chart 4.1 illustrates a typical demand structure, on daily basis, for a generic product. The demand is illustrated in chronological order. Please note that a peak has been excluded since it would otherwise compromise the appearance of the chart. The value of the peak was over 8000. The chart is drawn from statistics from the logistics centre in Poland West.

4.6 Lot-sizing

At the moment there is no company policy on lot-sizing, it is up to each production unit to determine its own lot sizes. There are a number of varieties of how lot sizes are decided and the two most common ones are decided by production and decided by the inventory control system, i.e. the Swedwood setup of a time-phased order point system with its weekly demand. Lot sizes determined by the Swedwood setup of a time-phased order point system equal the predicted demand specified on a weekly basis, i.e. the IKEA forecast and the existing orders for the specific week will determine the lot size. Lot sizes determined by the production have more influencing factors. Influencing factors can be production equipment, materials handling issues, type of product, and material restrictions.

Since many of the Swedwood production units are highly specialized with purpose built production lines with varying setup time, lot sizes need to be big in order to keep efficiency. Swedwood is continuously working with innovations that will decrease setup time since setup time has a substantial impact on the lot sizes. The aspiration for shorter setup times is suppose to enable lot sizes to be reduced.

Swedwood has four major categories of products; solid wood, kitchen, board on frame, and flat line. These products are very different in design and manufacturing methods which has a large impact on the lot sizes.

Sometimes material handling issues determine the lot sizes. Many of Swedwood's products are made of particle boards or Medium Density Fibre (MDF) boards. These different boards are often delivered to the production facilities on pallets and as very large boards. These boards are difficult to handle without the use of big counter balance forklifts, hence the whole pallet need to be processed at the same time.

Furniture production requires a lot of raw materials. Raw materials need to be stored properly and this requires much space. Since space for raw materials often is limited lot sizes can only be of a certain size.

There are no mathematical calculation methods for lot-sizing practiced at Swedwood at present.

4.7 Safety stock policy

The safety stock policy used by Swedwood at the moment is set by its customer IKEA. IKEA has ordered Swedwood to have a safety stock level equivalent of two weeks demand. Some production units keep two weeks production in safety stock instead of two weeks demand. There is no differentiation between different products regardless of lead time or service class. Some Swedwood factories have slightly higher safety stock levels for a few products due to long lead times and heavy work load.

There are four different service classes; S0, S1, S2, and S3. The S0 service class is the highest on and it requires a service level of 100 percent. The S0 service class is solely used for the kitchen segment. The reason for the high service level is that kitchens are sold as complete sets and hence all articles need to be in stock in order for IKEA to sell the products. The S1 service class is set at a level of 99 percent, the S2 at a level of 95 percent, and the S3 at a level of 90 percent.

In general Swedwood is quite good at maintaining their service classes at the requested level. In fact most of the products that are requested to have a service class equal to S2 or S3 often reach a higher service level than what is intended. The average service level for S2 and S3 category product is usually between 96-98 percent. As a result of the high service levels delivery security is fairly good where shipments are seldom lacking goods or are cancelled.

In the @-cap documentation it is described that the Serv1 definition should be used to calculate safety stocks. Most ERP-systems support calculations according to Serv1 but not Serv2. The implementation of @-cap has not been carried out on all of the production units just yet.

4.8 Swedwood Tibro

The Swedwood production facility in Tibro is one of the factories placed in Sweden. The production facility employs some 240 people with the majority in the manufacturing. Their main products are the chest of drawers with the family name Malm and the office table with the family name Galant. Of the two the Malm products accounts for the largest volume in sales. The production facility became a member of the Swedwood group in 1995 and it is one of few production facilities that not uses the ERP-system M3, instead the Jeeves ERP-system is used. The Tibro plant mainly serves the West-European market where the Great Britain market is by far the most prevalent.

Production

The manufacturing is based on production lines that are optimized for the Malm and Galant products. The flow through the factory is follows a U-shape and is more or less straight all the way through. The production line starts with a particle board being cut into smaller pieces and the cut particle board is then put on conveyers that run all through the manufacturing to the inventory. The second of the production process is to apply the veneer. After the veneer is applied the particle board is cut into its final shape and the edge bands are attached. The component is sent to a packing line where all sub-components are put into the final package.

Normally production is carried out in three shifts but both two and four shifts are utilized as well. The work load decides the number of shifts that are required. The Tibro plant does only have small buffers between manufacturing operations and all buffers are placed on the conveyer. The normal time for a product through the flow is two to three days depending on design. That is from when a MO is initiated until it is finished. The time for switching from one product to another is usually less than an hour. The output of the production is considered to be sufficient to meet customer demands.

Inventory

The inventory for finished goods in the Tibro production plant is located in the end of the U-shaped factory. In the inventory there are about 30 articles stored and all of them are put on pallets. There are two pallet sizes the IKEA-pallet, which measures 2000x800 mm, and the EUR-pallet. Storage consists of both racks and free stacking. The part of the inventory that consists of racks is automated, i.e. pallets enter the inventory on a conveyer and the pallet is put into the rack with the help of an automated forklift. In the rack there are small robots running on rails moving the pallets closer to exit where pallets are then taken out of the racks and on to the truck loading area. The maximum capacity of the racks and the free stacking put together is 12000 pallets which correspond to approximately four weeks demand. The size of the inventory is approximately 6500 square meters. The capacity of the inventory is seen as inferior and the management is investigating the possibility to expand the inventory further. The inventory has a turn-over rate of 20 times per year. Products that are kept in finished goods inventory are not classified according to any particular model but it is managed based on the consumption in the finished goods inventory.

The inventory control is quite complex at the Tibro production plant but it is in essence a supplement version of the time-phased order point system. The Tibro model uses more parameters to determine the size of the finished goods stock and how it shall be replenished. The model emanates from the MPS where the first step is to collect data. The data collected involve the forecast from IKEA, the inventory position of the article in question, released production plans for the article, capacity in bottle-necks, extraordinary demand, build-up of seasonal stock and in some cases the inventory position at IKEA's regional warehouses. In the second phase the actual need is calculated and it is determined whether or not an article should increase in stock. The third and final step is to release production orders to meet the demand. Much of the calculations carried out are manually in excel-sheets but all information derives from the ERP-system.

Over 80 percent of the articles kept in stock are required by IKEA to reach the highest level of service which implicates the S1 class. In the Tibro production facility this requirement is met not just by the 80 percent that are forced to but by all articles across the ranges. Availability is highly prioritized at the Tibro plant and the impact of a high capital deployment is subordinate the availability.

The safety stock level is established by two weeks demand, i.e. the amount kept in safety stock equals the demand during two weeks. The service level is fixed and does not change over the year but adjustments are made in connection to vacation closure. The safety stock level equals two weeks demand regardless of article and frequency.

The Tibro production plant does not measure delivery reliability or delivery security since IKEA perform these measures. Delivery reliability is high thanks to a supplementary check of goods that is being shipped while delivery security is at 80 percent. The delivery security of 80 percent can, according to the management, be explained by the freight forwarder since goods are rarely late from the production or inventory. The Tibro plant is using the FCA incoterm i.e. the plant is responsible for the products until loading is complete. The delivery security is not seen as a big problem since delivery reliability is good. The majority of shipments are sent directly to an IKEA store and only a fraction of shipments are sent to regional warehouses. The Tibro production plant is replenishing regional warehouses according to the Vendor Managed Inventory-principal, VMI, and orders to IKEA's regional warehouses are placed by personnel in Tibro.

4.9 Swedwood Älmhult

The Swedwood production facility in Älmhult is located not far from one of IKEA's regional warehouses and one of IKEA's administrative offices. The factory was acquired by the Swedwood group in 1991. Today the production unit has 360 employees where approximately 280 people work in production. The production unit manufactures doors and coverpanels to kitchen cabinets and wardrobes. The factory supplies all markets in the world and was just until recently the only supplier for its products, now the Swedwood factory in Portugal produce some of the articles as well.

Production

The manufacturing is carried out in both line-production and more of a work-shop based production. In the work-shop based production goods are transported on pallets between different operations, the line-production on the other hand uses conveyers to transport goods between machines and all the way to the inventory. Both production types are highly automated with very little manual labour. The production flow is very complex, products does not have a straight way through the factory. There are 14 different production flow groups in production which are run every week. In production products can be differentiated either by the first operating machine, this is called push, or it can be determined by its last operating machine, this is called pull. E.g. the product has the same characteristics for many products until its last operation where every product becomes specific.

Production is carried out in three shifts plus work on weekends, i.e. production is carried out in six of seven days a week. There are about 400 articles to produce all of which are based on MDF boards. The MDF boards are bought pre-cut and are kept in stock. The normal production lead time is two to eight days. The average batch size is 2300-5000 pieces.

Inventory

The inventory is located across the street relatively the production. All 400 articles are kept in stock and all of them are put on pallets. The quantity on a pallet varies between 42-306 pieces depending on article. The most common method for stacking pallets is in racks but some free stacking do exists. By using racks the Swedwood production unit in Älmhult is able to apply First-In-First-Out-principal, FIFO, on its finished goods stock. The inventory is operated by forklifts. The inventory has a maximum capacity of roughly 8000 pallets or 900 000 pieces. However, at the time when this study was made the inventory was full and an additional inventory was rented, 907 000 pieces was kept in stock. The inventory has a turn-over rate of 15 times per year and the size of the inventory is 10 000 square meters. The inventory does not apply any rules or classification of where goods should be stored. When goods are to be put in racks the forklift driver will get a proposition for the nearest possible location to store the goods. A classification system was previously used but was not seen useful.

Of the 400 article in stock 50 percent are products for the American market although this market only represents 10 percent of total sales. As a consequence these products are kept in stock for a longer time than the products for the rest of the world. Of all products kept in stock 40 percent of the articles accounts for 80 percent of the volume, 60 percent of the articles accounts for 92 percent of the volume, and 80 percent of the articles accounts for 96 percent of the volume.

The inventory control at Swedwood Älmhult is quite complex and sophisticated. As most Swedwood production units a time-phased order point system based on forecasts, customer orders, and safety stock is used. However, unlike the Swedwood standard the production facility in Älmhult has numerous add-on help-programs to M3. The first program that is used is called Demand Planner, DMP. DMP is a tool that handles many aspects of forecast. The program helps the planners to validate forecasts and to determine the need for a specific production group or article amongst other things. The result from the DMP is then used in another add-on program called Supply Chain Planner, SCP. SCP is more complex than DMP and utilizes more parameters. In essence the program is a tool for master production scheduling that takes a supply chain perspective when suggesting on a production plan. The result from the SCP is used as a base for the MPS that is to be set. When the MPS is set an application called Movex Advanced Production Planning, APP, is used to plan the production more in detail, i.e. specify when a specific products shall be produced. Unlike other Swedwood production units the Älmhult factory has a planning horizon of four weeks instead of two.

Additionally Swedwood Älmhult uses an advanced program for ABC-classification called ABC-tools. The program is partly used to determine safety stock levels and is based and a double criterion ABC-classification using volume and frequency. The majority, 80 percent, of products produced in Älmhult are of service class S0 whereas the rest of the products are in service class S1. The average measured service level is over 99 percent. The safety stock level is set at two pallets to every destination within Europe, there are five destinations, and one pallet of every article to US destinations, there are two destinations. Safety stock levels are revised at least once every six months. If the demand is notably changed safety stock levels are also revised.

The production facility delivers goods to four different types of customers. The largest customer is an IKEA regional warehouse called low-flow which accounts for about 50 percent of the volume. With shares of 20 percent of total volume, there are both transit orders and orders from CDC, which is a smaller IKEA regional warehouse. Transit orders are delivered to IKEA's regional warehouses but are just merged with products from the warehouse; products are never put into the warehouse. The remaining 10 percent are deliveries to regional warehouses in the US. Swedwood Älmhult does not deliver any goods via direct delivery to stores since the smallest size of a delivery, a pallet, is too much for one store. The lead time of in which an order has to be delivered is in 90 percent of all cases 2-7 days. Swedwood Älmhult requires a certain fill-rate in order to ship goods and longer lead time than the normal 2-7 days is often caused by an insufficient fill-rate.

The only measurement that Swedwood Älmhult measures them self is the number of orders that are being cancelled. If an order is not available to delivery when it is placed it is cancelled and re-placed the following day. All other benchmarking is carried out by IKEA.

4.10 Swedwood Poland West

Swedwood Poland West is the biggest production unit within the Swedwood group and it is also one of the biggest furniture factories in the world. The factory became a member of the Swedwood group in mid 1992 and the factory is located in the small city Zbąszynek. The production unit consists of three factories Babimost, Zbąszynek, and MPS. The MPS and Zbąszynek factories are located in Zbąszynek while Babimost is located 12 kilometres south of Zbąszynek. Put together the factories employees more than 3000 people with the majority in production. The main product groups for Poland West are Mikael, Odda, Lack, Expedit, and Bestå. The production unit supplies the whole world but Europe is the main market with a share of 75 percent of the volume. The production unit Poland West is presently working with the implementation of @-cap.

Production

The production in the production plants can be seen as a mixture between a work-shop and line based production. The products are transported on conveyors into the operating machines but between different operating machines there are in most cases no conveyers, instead goods are transported by forklifts or manually operated rail-guided transport wagons. The flow through the factories runs like a zigzag from one side to the other. In conjunction with the factories in Zbąszynek there is a component plant supplying all three factories with goods, goods from component plant is used in all stages of production. The setup time for changing products is varying between no time at all up to an hour. The products produced in the production unit are made out of particle board, chip board, MDF board, or High Density Fibre (HDF) board.

Production is normally carried out in three shifts five days a week but sometimes weekends are used as well. In the production there is a lot of manual labour, it is not uncommon to have six people or so working at the end of a conveyors and stacking components on to pallets. The production units produce some 300+ articles and the average batch size is about 5000 pieces. The production lead time is 1-7 days depending on the MPS.

Inventory

The logistics centre in Zbąszynek is located in close connection to the production facilities with only a small passage in between. The Zbąszynek factory is connected to the logistics centre via two corridors above ground, in these corridors pallets are transported on conveyors into the logistics centre. The MPS factory has an inventory of its own but it is a part of the logistic centre it is also connected to the main building via a corridor above ground. Goods are delivered into the main building of the logistics centre to merge with products from the rest of logistics centre. When pallets have entered the logistics centre via the corridor a lift lowers the pallet and a forklift driver put the pallet in storage. All pallets in the inventory are stacked on the floor according to the free stacking principal. The maximum capacity of the logistics centre is 83 000 cubic meters or approximately 55 000 pallets which is managed in an area of 56 000 square meters. The inventory has a turn-over rate of 20-24 times per year due to an outbound delivery of 6000 pallets a day. The logistics centre has its own loading dock for trains and it has also the possibility to load 17 trucks at the same time.

Products in inventory are classified according to the ABC-classification model. The ABC-classification is used according to the @-cap principal in order to decrease pallet transportation.

Swedwood Poland West delivers to all customer types where direct delivery accounts for 75 percent of orders, franchise stores account for 13 percent, IKEA regional warehouses account for 10 percent, and transit orders account for 2 percent. However in terms of quantity the regional warehouses account for more than 60 percent of the total volume. The lead time from order receipt until dispatch is normally five days. The logistics centre does not measure delivery security since this is done by IKEA. Delivery security for financial year 2008 was in average 80 percent. However, the logistics centre measures delivery security from production to the logistics centre and the security is in average 80 percent.

The inventory control is as in most of Swedwood's production units a Swedwood setup of a time-phased order point system. Forecasted demand is revised by planers and from the SPI-file a proposal on a production plan is made in an excel-sheet. The proposal is then adjusted in collaboration with production managers to assure that production capacity is adequate for all products. The MPS is set one week in advance and after the adjustments made the production plan is entered into M3. Note that all planning is made in M3, the excel-sheets are only used to visualise the plan and to facilitate discussion. The planners do not use ABC-classification but do take the service class into consideration when planning the MPS.

The product range kept in stock in the logistics centre in Zbąszynek is represented in all the IKEA service classes. The S2 class is the most common which is required on 50 percent of the articles, the S3 as the second most common with a share of 27 percent, and the rest is S1 classified. The S2 and S3 are maintained at requested levels while the S1 falls a bit short with an average of 98 percent, financial year 2008. The logistics centre does not measure service levels but it receives reports on performance from IKEA.

The logistics centre in Zbąszynek has recently started to use the Serv1 definition to calculate safety stocks. At first the calculations were carried out manually but now when the amount of historic data is sufficient it is carried out by M3. It is estimated that 40 percent of all articles are using the algorithm to calculate safety stocks. The safety stock levels are revised manually whenever demand is changed and may override the service level set by M3. There is also a maximum level of safety stock set manually sometimes since the safety stock otherwise would be too big.

5 Analysis

This chapter will analyse the empirical data according to the theoretical framework. The chapter starts with an analysis of a classification policy and continuous with forecasts and control systems. Furthermore the company lot-sizing policy is evaluated followed by an analysis of the demand structure and safety stocks. The chapter is concluded with a comparison of the three production units presented in previous chapter. The statistics used in this chapter derives from three production units; Poland West, Tibro, and Malacky II where Poland West is most represented. The statistics used to analyse forecast is based on examples of IKEA's best forecasts. Due to its sensitive nature, the background statistics to much of the analysis will not be presented.

5.1 Classification

At present the service classes set by IKEA work as a sort of classification. However, to solely rely on a classification set by the customer has a few problems. One of the biggest problems associated with following the service class classification is that many production units have the majority of products in the same category and therefore products are having the same importance. To apply service classes as a classification would then be useless. Another problem is that the service classes do not embrace the frequency in which the product is being ordered or how big the volumes are.

Another problem with the lack of a company policy on classification is that the production and the logistics centre use different classifications and for different purposes. Consequently the production will indirectly make prioritisation affecting inventory control since service classes are determining the MPS. The result of such a system could be ineffective inventory control with negative effect on delivery reliability, e.g. while planning the MPS a low frequent S1-product with a stock level slightly below average could be prioritised over a S2-product with high frequency with the same inventory level due to its higher service class. According to a double criterion ABC-classification S2-product would be prioritized since it would be classified as an A-category product while the S1-prduct would be a B-category product. This is further illustrated in *table 5.1*.

Service Class	Frequency		
	High	Medium	Low
S1	A	A	B
S2	A	B	C
S3	B	C	C

Table 5.1 illustrates the double criterion ABC-classification in practise.

A thinkable solution to these problems is to combine the service classes with the ABC-classification into a multiple criterion ABC-classification. The usage of a multiple criterion ABC-classification would create a joint platform for the logistics centre and the production which would simplify prioritisation. This in turn will lead to making the inventory control more adjusted to the real customer demands. Suitable criterions to use in a classification are the both criterions used today, frequency and the service classes. Volume is also a criterion to be considered if it is combined with the service classes. However there is a disadvantage to use the volume as a criterion; it is not used at present while frequency is. Another desirable solution is to apply the multiple criterions classification with both volume and frequency which would be good from a flow-perspective. Unfortunately this solution is not plausible since it does not account for the service classes.

A company common policy on classification, with double criterions ABC-classification, would be beneficial for inventory control since it would allow a more elaborate control policy to be applied. If a multiple criterions classification with frequency was to be used it could also be used to manage turn-over stocks to a certain extent. Products in the A-category would be produced more frequently in smaller batches hence allowing turn-over stocks to be decreased. In contrast, the C-category products would be produced more seldom in larger batches and therefore requiring larger turn-over stocks.

Implementing a multiple criterion classification system should not cause too much problem. Multiple criterions ABC-classification is supported by M3 and the single criterion classification is already in use in the logistics centres. The use of a classification requires statistical data and some production units may lack sufficient data but it could easily be gathered within a year. The implementation would be easier to realise if the concept of multiple criterions ABC-classification was to be adopted into the @-cap documentation. The current use of the ABC-classification described in @-cap is good but applying the ABC-classification to inventory control as well would contribute even more to increase efficiency.

5.2 Inventory control

5.2.1 Control system and planning

The time-phased order point system provides a good starting point for inventory control. Theoretically the Swedwood setup of a time-phased order point system does not require more turn-over stock than what is forced by production cycles. The demand is identified via the IKEA forecast and hence the turn over stock is only to cover the consumption during a production cycle. In theory the only turn-over stock needed is a stock containing goods the short time between production and dispatch. This in turn implies that the only goods kept in the inventory should be safety stocks.

The Swedwood group's order system includes turn-over stocks and in combination with fixed planning point for production planning, which is basically replenishment orders for the logistics centre, the inventory control system resembles a periodic ordering system rather than a time-phased order point system. Of course the two weeks planning horizon is attached with some uncertainties but these are to be covered by the safety stock not a turn-over stock. It might be necessary for production batches to be of a certain size which would leave some goods as turn-over stock. If the inventory control system is supposed to be a time-phased order point system with fixed production cycles, the turn-over stocks should be kept at an absolute minimum. The turn-over stocks in such a system should only be the size enforced by the time between production cycles, i.e. if a product is produced once every two weeks the maximum size of the turn over stock should be the size of the forecasted demand for these two upcoming weeks plus the calculated undershoot. In average such a product should have a turn-over stock of one week plus the undershoot.

The system has a few other problems as well if it is supposed to be a periodic ordering system. One problem is the policy on replenishment orders which seems to be none existing. A periodic ordering system should be either replenished with multiples of the EOQ or with a batch intending to get the inventory position to its maximum value.

Due to this setup the Swedwood inventory control system is probably best seen as a hybrid of a time-phased order point system and a periodic ordering system. Unfortunately the setup combines the downsides of the two ordering systems; high capital deployment from the periodic ordering system, due to large turn-over stocks, and the uncertainty that production face when basing the MPS on the IKEA forecast from the time-phased order point system.

At present, the ATP does not comprise the effect undershoots when checking whether or not the order can be satisfied. Undershoots have a noticeable effect on service towards customers, hence the undershoot should be comprised in the ATP check. A possible solution would be to reduce the inventory position with the calculated undershoot. The system would then trigger a DO-proposal to be sent out well in time. This will potentially lead to better service towards IKEA. However, when re-programming the ATP it must be possible to see the actual stock-on-hand, i.e. the inventory position decrease should only trigger a DO-proposal but it should still be possible to allocate goods.

As the setup is today the turn-over stocks might serve as buffers covering fluctuations in demand and possibly problems in production but these uncertainties are to be covered with the safety stock.

If the turn-over stock is removed as buffer, the fluctuations in demand might entail an increase in safety stocks. A calculation of safety stocks in accordance with the @-cap suggested method, Serv1, is presented in t*able 5.2* below.

	Number of Articles			
Service level / Weeks	**90%**	**95%**	**99%**	**Total**
0 < 2	16	40	13	69
2 < 4,5	34	42	14	90
4,5 < 9,5	9	11	15	35
Total	59	93	42	194

Table 5.2 illustrates the safety stock level, according to Serv1, expressed in coverage weeks.

The average coverage for all articles used to create *table 5.1* would be approximately 3.1 weeks which is not a particularly large increase from the current policy of 2 weeks coverage. In the calculation all products are set to have the same lead time and standard deviation for lead times.

However, the turn-over stock might serve as a buffer for the production. If the turn-over stock is used as a buffer it can not serve as a capacity buffer. The demand for products is constant which in turn implicates that the capacity need is constant. Inferior production capacity would then eventually result in stock-outs constantly for some products which is not the case. It is more plausible to assume that it serves as a time buffer. The need for a time buffer suggests that there would be some problems with the detail planning. Problems with the detail planning are most likely to be educed from the timeframe in which the detailed planning is carried out.

If the timeframe were to be extended an enforcement of enlargement of the turn-over stock size would have to be made which would increase capital deployment even further. Additionally, if the timeframe is to be extended the production must rely on more long-term IKEA forecasts. In general the quality of a forecast deteriorates the longer in advance it is made. However, a longer timeframe would enable production to run very smooth and at a high capacity utilization. A long planning horizon will allow the planner to sequence products in such a manner that setup times could be reduced to an absolute minimum.

On the contrary to an extended timeframe a shorter timeframe would be more agile and could easier cope with fluctuations in demand. It would therefore entail production to base manufacturing that would reflect more on the actual customer demand. Many of the uncertainties could be minimized since the customer order point would get nearer to the customer. In general the IKEA forecasts get better the shorter the timeframe is. The use of turn-over stocks could then be distinctly reduced. The downside with a shorter timeframe is reduced capacity utilization due to more setups caused by smaller batches. A decrease in capacity utilization would raise the cost for production in the same time as the inventory related costs would decline.

An alternative to the two different planning timeframes could be to combine them. Some of the MPS could be planned according to the existing timeframe or an extended timeframe while the rest would be planned within a shorter timeframe. The long-term planning could fill the MPS with MOs covering slightly less than the average weekly demand. The short-term planning could then fill the rest of the MPS with MOs. These MOs should be based on the newest forecast or in the extreme case actual orders. However to place MOs upon actual orders is not realistic since the products produced have to be cheap hence focus on cost efficiency, i.e. capacity utilization is very important. With the combination of long-term and short-term forecasts capacity usage could be kept high without the loss of agility. An example of this approach is presented in *figure 5.1* below.

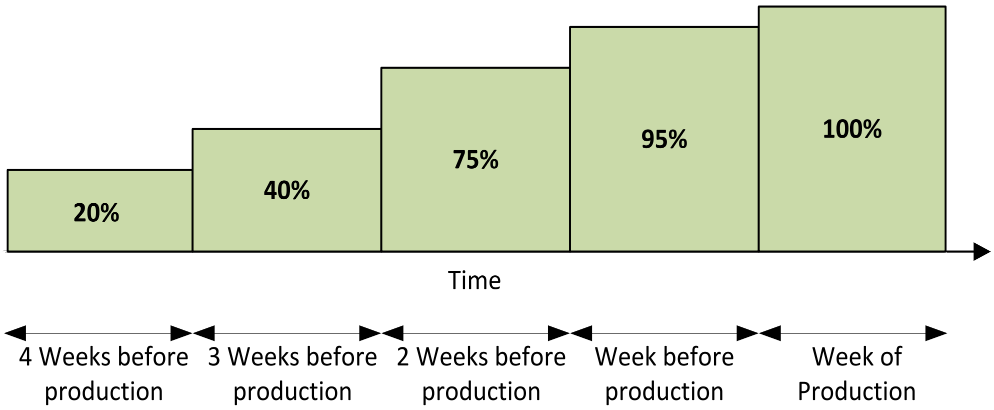

Figure 5.1 illustrates an example of combining long- and short term planning. The blocks illustrate the capacity utilisation planned and how it is augmented during the time.

In *figure 5.1* the long and short-term planning horizons are combined into a dynamic planning period. It is still possible to have fixed planning points in the dynamic planning period but the difference is that it has several points. Each week has a planning point where DOs, or fractions of DOs, are added to the MPS and the total capacity utilisation is gradually augmented.

Another aspect of planning that need to be addressed is the high utilisation planed. When the planning is made to utilize the production to 100 percent there are no possibilities to make any changes if any problems occur. By leaving some slack of 5-10 percent in planning the production may run smoother. To leave some slack in the production schedule does not have to raise the cost for production. Capacity utilisation today is significantly lower than the planed i.e. there is a low correlation of planned capacity and actual capacity utilization. It is even possible that by leaving some slack in planning the actual capacity utilization might get a better yield. It also has potential to evade the problems with re-planning. However there is always the risk that capacity utilization might decrease.

Planning is largely affected by the quality of forecast and fluctuations change capacity requirements rapidly. However, less fluctuating forecasts do not solve the irregularities in weekly demand even though it reduces the effects of it. Much of the irregularities are caused by IKEA's regional warehouses. The explanation to why is to be found in their inventory control principles. The system used by the regional warehouses resembles a classic order point system, with the difference that instead of quantity the inventory level is expressed in time. Combining, what is supposed to be, a time-phased order point system with a regular order point system could entails negative consequences depending on how strict IKEA follows the their inventory control principals. In an order point system ordering does not take place until the order point is reached. The forecast will have to pin-point when the order point will be reach very well for Swedwood to anticipate the order. If the forecast evens out the projected need during a couple weeks Swedwood is likely to see the forecasts as invalid and ignore them. Since it is most unlikely for IKEA's regional warehouses to change their inventory control system upon request wherefore another solution has to be found.

For Swedwood production units to change inventory control system is not an eligible solution either. Changing to order point system would hardly help to even production since it would require larger batches. The order point would have to be set very high due to the large undershoots that would occur with such a system. The result of introducing an order point system would most likely be increased capital deployment rather than decreased. To use the two-bin technique would not be suitable since the system is built on principles not coinciding with the current aspiration to reduce capital deployment at Swedwood. In conformity with the two bin technique the periodic ordering system would increase the capital costs. To apply any of the previously mentioned techniques have the big advantage and it is independence of IKEA forecast usage. To use the more elaborate variant of the time-phased order point system used in Tibro is for most units not an option since it is very time consuming if the product range is anything else than very small.

Some of the Swedwood production units are using VMI to supply regional warehouses. The use of VMI is a very attractive approach for both parties. The benefits for Swedwood are obviously an increased control over the flow since the logistics centres will be responsible for replenishing regional warehouses. Production planning would be easier since replenishment orders could be placed when suitable given that the balance in the regional warehouse is within its boundaries. If VMI was applied the regional warehouses could be replenished more frequently since Swedwood would be responsible for order placement instead of IKEA. This would change the ordering pattern from once every 2-3 moths as it is in extreme cases. The result for Swedwood would be a demand without enormous peaks, which would even production, and the result for IKEA would be a decrease in capital deployment since warehouses are replenished more frequently with smaller batches. To replenish warehouses with an even frequency requires a steady demand from stores to regional warehouses. The order-rate today from stores to logistics centres suggests that this is the case. Based upon the ordering from stores to logistics centres the demand for a generic product is quite stable. The regional warehouses and the logistics centres have same function for the stores today which implicates that the demand pattern in a logistics centre ought to be transferable to the regional warehouses.

There are a few other disadvantages with the Swedwood setup as well. Each production unit has its own setup and are running on different versions of ERP-systems. Different versions and setups restrict the possibilities to connect all production units into a central ERP-system. There are also production units not running on the standard system M3 which obstruct the integration process even more. Connecting all production units via a central system has many benefits. By connecting the production units into a central system certain functions could be centralised e.g. benchmarking and system development which has potential to save costs. Centralised functions would not just have cost saving potential but it would also provide production units with support and expert help more rapid than previously. It would also allow top management to review production units without visiting them or requesting data from each production unit. The downside with centralisation is that it is time consuming and it requires a lot of work.

5.2.2 Forecasts

Another problem with the current setup lies in customer forecasts. Since production is mainly based upon forecasts with fluctuations from week to week, it becomes difficult for the production to run smoothly. The IKEA forecasts changes over time as can be seen in *table 5.3*. During the period presented in *table 5.3* the order intake is more fluctuating than normally, however due to lack of old SPI-files the example in *table 5.3* will have to do. In contrast to the forecast the weekly actual ordering is less fluctuating; of course orders from regional warehouses have a large negative effect on ordering stability. The relation between forecasts and orders are presented in *table 5.3* below.

SPI	42	43	44	45	46	47	48	49	50	51
41	8970	8220	**7920**	6810	6990	7200	7830	8550	7560	8190
42		8940	8190	**6720**	7230	7020	7530	7650	7740	8280
43			8850	7380	**7011**	7230	8480	7860	7819	8370
44				9710	6930	**6800**	8220	8119	7740	8180
45					8700	7500	**7680**	8310	7530	8850
46						10050	7560	**7650**	7530	8370
47							9570	8040	**7140**	7740
48								9060	7440	7590
49									9480	8190
Order			5520	7560	6210	10290	8100	6960	10800	

Table 5.3 illustrates how IKEA forecast are updated. The highlighted cell marks the forecast that is being used to set the MPS. The left column represents the SPI-file, the following columns, left to right, illustrates the projected need for week 42-51.

The weekly absolute divergence from the forecasts versus orders is further illustrated in *chart 5.1*.

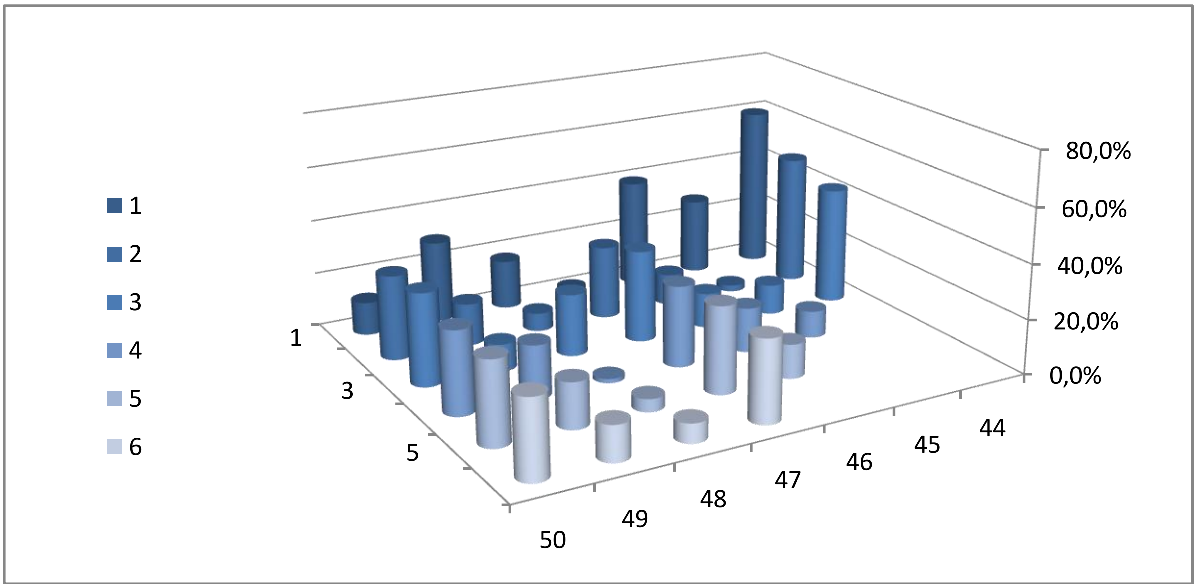

Chart 5.1 illustrates the absolute divergence for each week. The Y-axle (marked 1-5) is presenting the age of the SPI-file in weeks, the X-axle (marked 44-50) presents the week for which the forecast is aimed, and the Z-axle (marked 0-80%) illustrates the absolute divergence between forecasts and orders. Note that for the bars in rows 4-6, values have been excluded i.e. the absolute divergence is not naught initially but the graph starts in week 45-47.

The product illustrated in *table 5.3* and *chart 5.1* has a cancellation rate of naught percent during the time period presented. There are additional illustrations of forecasts versus orders presented in *appendix 2*. As t*able 5.3* and *appendix 2* illustrate the quality of forecasts changes over time. In some cases the expected quantity of the forecast is both amplified and reduced quite a lot just the week before ordering compared to prior forecasts. Cancelled orders may cause IKEA to increase the short-term forecast to compensate for late deliveries the previous week. If orders are cancelled continuously IKEA is likely to increase their safety stocks to cover the shortages, in the short-term perspective this may be perceived as an increase in demand. When the safety stocks eventually are replenished the forecast and the demand will drop rapidly which could explain sudden reduces in forecasts. However, this is not the case for the products presented in this master thesis since all products except one has a cancellation rate of naught. Products with a high cancellation rate could cause forecast fluctuations though.

IKEA's intention to increase B-order may cause forecast and order instability during a transition phase. If the change is instant the forecast and ordering will only be affected largely during short period. The logistics centre will experience a large increase in received orders which would be perceived as a large increase in sales. If the logistics centres are not aware of the transition the result is likely to be a stock out or redundant stock. However, if the stores use both regional warehouses and logistics centres as suppliers the forecast and ordering could be more pendulous. Swedwood would have difficulties to know the actual demand since the logistics centres will be unaware of if orders from stores represent the total need or if some of the need is covered by regional warehouses. A swift change would probably cause larger variations initially but would be corrected more quickly than the step-by-step transition.

Another possible influencing factor on forecasts is sale campaigns. It is imaginable that the sales expectations for a certain product could be a bit ambitious and when the forecast is put together at

IKEA the planner may be unaware of local campaigns. However, if the forecast is too optimistic the following forecasts would have to be adjusted down as a consequence of high stock levels and that is not the case. Forecast drops are probably cause by stores ordering goods from both regional warehouses and logistics centres. If deliveries are late or unreliable the store may increase the share ordered goods from regional warehouses which initially will make the forecast drop just to bounce back at a higher demand when the regional warehouse is starting to be depleted.

To asses which IKEA forecast to use a comparison of different forecast versus orders is presented in *table 5.4* below.

Age of forecast (SPI)	**1**	**2**	**3**	**4**	**5**	**6**
Average divergence	21,7%	29,1%	30,2%	33,6%	38,6%	40,3%

Table 5.4 illustrates the absolute average divergence. The table is based on the average of 9 articles during a 2 month period.

As expected the most recently reviewed forecast is the one that is the most accurate. Interestingly the difference between a forecast from two weeks and a forecast from four weeks is a mere 4.5 percentage points. *Table 5.4* is suggesting that if MOs are based on the most recent forecast the stock serving as buffers could be reduced without a raise in stock-outs. To plan the MPS partly on more long-term forecast as suggested in the previous chapter is possible as long as the planned quantity is clear of the uncertainty of the IKEA forecast.

Since the weekly ordering is less fluctuating than forecasts, a possible solution could be to base the MPS upon the previous actual ordering rather than forecasts. Such a setup would smoothen some of the irregularities that the production face presently. The downside of using order statistics to generate MPS is its inability to capture orders placed well in advance and sales campaigns that requires supplementary pieces. This problem could however be manually adjusted since the information is available in the SPI-file. Sadly increased manual work with planning requires a lot of work hence it is not a desirable solution. If the inventory control is not time-phasing the MPS will be based on orders in real-time which make IKEA forecasts redundant.

An alternative to forecasts and actual ordering could be the use of a forecasting method e.g. moving average or exponential smoothing. Both these algorithms are supported by M3 hence it does not require manual interference. A simulation of how suitable moving average and exponential smoothing are is presented in *table 5.5-5.7* below. The simulation is made for 10 articles during five and six weeks for moving average and seven weeks for exponential smoothing. The tables show the absolute difference in percent between the actual orders and the expected ordering according to forecast with or without correction. Please do note that article 9 has a quite large peak (two times the mean) to test how well the models cope with fluctuations.

Article	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
N = 2	36,0%	26,9%	18,0%	17,5%	20,3%	14,3%	20,7%	21,6%	52,2%	22,7%
Forecast	33,7%	35,4%	16,3%	19,9%	7,4%	39,1%	16,5%	15,0%	24,8%	11,4%

Table 5.5 illustrates the accuracy of forecasts and forecasts according to moving average versus actual orders. The moving average is based on two weeks average and it is simulated for 6 weeks.

Article	1	2	3	4	5	6	7	8	9	10
N = 3	37,5%	30,6%	24,1%	11,5%	22,0%	17,0%	20,7%	24,7%	48,8%	23,1%
Forecast	35,7%	30,5%	14,9%	16,9%	6,8%	36,6%	15,4%	16,7%	29,2%	12,9%

Table 5.6 illustrates the accuracy of forecasts and forecasts according to moving average versus actual orders. The moving average is based on three weeks average and it is simulated for 5 weeks.

Article	1	2	3	4	5	6	7	8	9	10
α = 0,05	28,4%	20,9%	20,1%	19,9%	17,3%	16,3%	14,1%	24,7%	40,9%	25,9%
α = 0,10	27,3%	19,8%	19,5%	20,0%	21,6%	15,7%	13,2%	27,2%	40,2%	26,8%
α = 0,15	26,3%	19,1%	18,9%	20,1%	31,8%	15,4%	13,2%	30,7%	39,6%	27,7%
α = 0,20	25,3%	18,8%	18,3%	20,2%	42,0%	16,2%	13,1%	35,1%	38,9%	28,6%
α = 0,25	24,4%	18,4%	17,7%	20,3%	52,2%	17,5%	14,2%	39,5%	38,2%	29,5%
α = 0,30	23,9%	18,1%	17,1%	20,4%	62,5%	18,8%	18,2%	43,9%	37,6%	30,4%
Forecast	29,2%	40,6%	16,8%	18,9%	8,9%	40,2%	15,4%	15,9%	48,5%	14,1%

Table 5.7 illustrates the accuracy of forecasts and forecasts according to exponential smoothing versus actual orders. The Exponential smoothing has been tested with values from 0,05-0,3.

According to the simulation there are no real gains if the moving average is chosen on the contrary the IKEA forecast is equal or better in most cases. The moving average based on two weeks seems to be better than the one based on three weeks. However, it has to be stressed that the test period is fairly short due to insufficient forecast data. The exponential smoothing is a bit better than the moving average but is not significantly better than the IKEA forecasts; it is more or less equal. There is however an advantage with the exponential smoothing and it is that it stabilises the difference between actual order and forecasts. Also M3 has a function alerting when demand arises quickly and allows managers to manually correct forecasts making them more even. More stable forecasts have the opportunity to level off production and ease planning.

To analyse the Swedwood forecast consumption method with one-way negative autocorrelation a comparison between no corrections at all versus the forecast consumption method is presented in *table 5.8* below.

Article	1	2	3	4	5	6	7	8	9	10
No adjustment	10,8%	40,7%	9,0%	21,3%	8,3%	46,7%	7,8%	4,3%	41,7%	11,3%
Forecast consumption	57,5%	51,1%	30,7%	152,9%	82,7%	509,0%	37,9%	28,3%	41,9%	81,4%

Table 5.8 Illustrates the difference between the sum of all orders versus the forecasts for a period of 10 weeks.

As the comparison shows the effects of forecast consumption with negative one-way autocorrelation has a large negative impact. It is also important to point out that the test is based on previous actual orders where forecast has an absolute average diff between order and forecast of 25 percent per week and article.

5.3 Lot-sizing

The method for determine lot sizes at Swedwood today resembles the principles in the estimated order quantity method. Due to materials handling issues the batch size is often restricted by the quantity of raw materials stacked on a pallet or a number of pallets which make the model suitable since the batch size is not calculated according to any specific method. However, the drawback with the method is its inability to account for economic factors when deciding on lot sizes. Methods comprising economic factors are the EOQ-model and the Silver-Meal algorithm.

If a multiple criterions ABC-classification is practiced one of these methods could be used to establish batch sizes for some products. The Silver-Meal algorithm is less used than the EOQ-model and besides it is not supported by M3 hence it is not a pleasing option. In contrast to the Silver-Meal algorithm the EOQ-model is supported by M3. The use a model for batch-sizing is most suitable for products in the C-category. C-category products will be produced more seldom than others and consequently in larger batches. The EOQ-model has the potential to minimize the cost for these batches and this opportunity should be investigated further. It is also possible to analyse if some B-category products could be suitable to be lot-sized according to the EOQ-model, particularly products with lower frequency. The A-category products on the other hand is likely not to be suitable for lot-sizing hence these products are supposed to have a high availability at a low capital deployment which becomes difficult to realise with EOQ-model.

The EOQ-model in M3 does only support the standard calculation of economic order quantity and not the one with limited production rate. Since the production capacity at Swedwood production units is limited the regular model might generate lot size proposals that are not possible to produce which could make the model useless. If the EOQ-models should be used or not depends on product demand for the specific product and where products are produced.

The biggest problem if the EOQ-model was to be applied in Swedwood production units would be the materials handling issues.

5.4 Demand structure

The annual growth of IKEA is a privilege few companies experience, especially since it is continuous. An annual growth of 10-20 percent imposes tough demands on suppliers. Luckily the demand is quite stable during the year without any dramatic demand changes which in turn makes inventory control easier.

As describe the J-orders have a large impact on the stock levels of logistics centres but there are also advantages with these orders and these are the possibility to cancel the order and it is easier to foresee a coming order via order statistics. The size of a J-order itself is in most cases not a problem with the current safety stocks but the range of products ordered is. E.g. consider five J-orders including 10-15 order lines each. The orders are likely to cause a depletion of safety stocks for the articles that are being ordered which in turn will generate a need for replenishment. To replenish all articles ordered will take time.

In contrast to J-orders B-orders are smaller and a single order does not have a particularly large impact on stock levels. However, many orders have a large impact. In *chart 5.2* below illustrates the number of confirmed orders per day for a two month period.

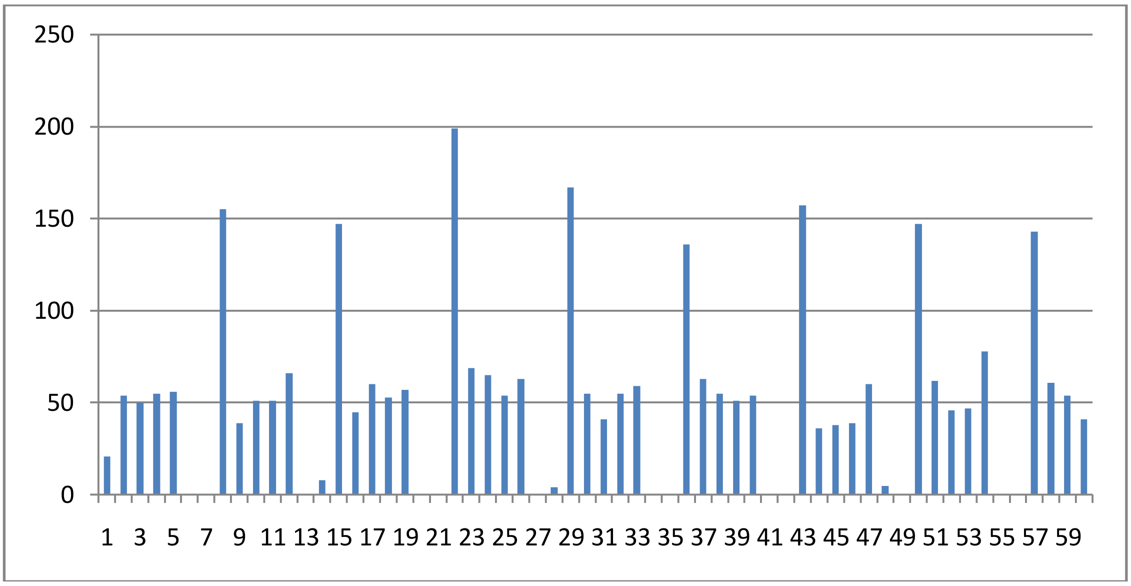

Chart 5.3 illustrates confirmed orders. The chart covers a 2 month period and values are in chronological order.

As the chart illustrates confirmed orders does follow a regular pattern. The chart suggests that the pattern is cyclic i.e. peaks often occur at the same day of the week. Most order are confirmed on Mondays which is further illustrated in *table 5.9* below.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Total
Orders Confirmed	1447	521	488	481	678	25	39	**3679**
Percentage	39,3%	14,2%	13,3%	13,1%	18,4%	0,7%	1,1%	

Table 5.9 illustrates the distribution of orders during weekdays.

The explanation to the appearance of the confirmed order pattern is likely to be found in the order placement from IKEA. The order intake (requested order day) per day is further illustrated in *table 5.10*.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Total
Orders Requested	1637	457	476	499	619	0	0	**3688**
Percentage	44,4%	12,4%	12,9%	13,5%	16,8%	0,0%	0,0%	

Table 5.10 illustrates the requested order day by IKEA

The product illustrated in the two tables above has an agreed lead time of five days. The data in the two tables is from early financial year 2008. As *table 5.10* illustrates the majority of orders are requested on Mondays while no orders, during the investigated period, are requested on weekends. A possible explanation to the pattern is that the stores' stocks are depleted by the weekend sales. By comparing both tables above an evident match can be detected. Obviously Swedwood will have trouble coping with the big workload on Mondays but none the less a lot of orders are confirmed on this requested day. It appears as if the stores do not place orders with a requested arrival on weekends. However if some of the requests for Mondays were to be set one or two days earlier many of the problems with peaks should disappear. By changing requested order day to also include weekends is likely to increase service versus IKEA in terms of delivery security.

To establish what the typical demand structure looks like the size and frequency of orders is interesting to observe. The easiest way to do this is to make a chart out of frequency and size. This will further be denoted as a frequency function and is not to be mistaken for a mathematical frequency function. In *chart 5.3* below a typical frequency function is illustrated.

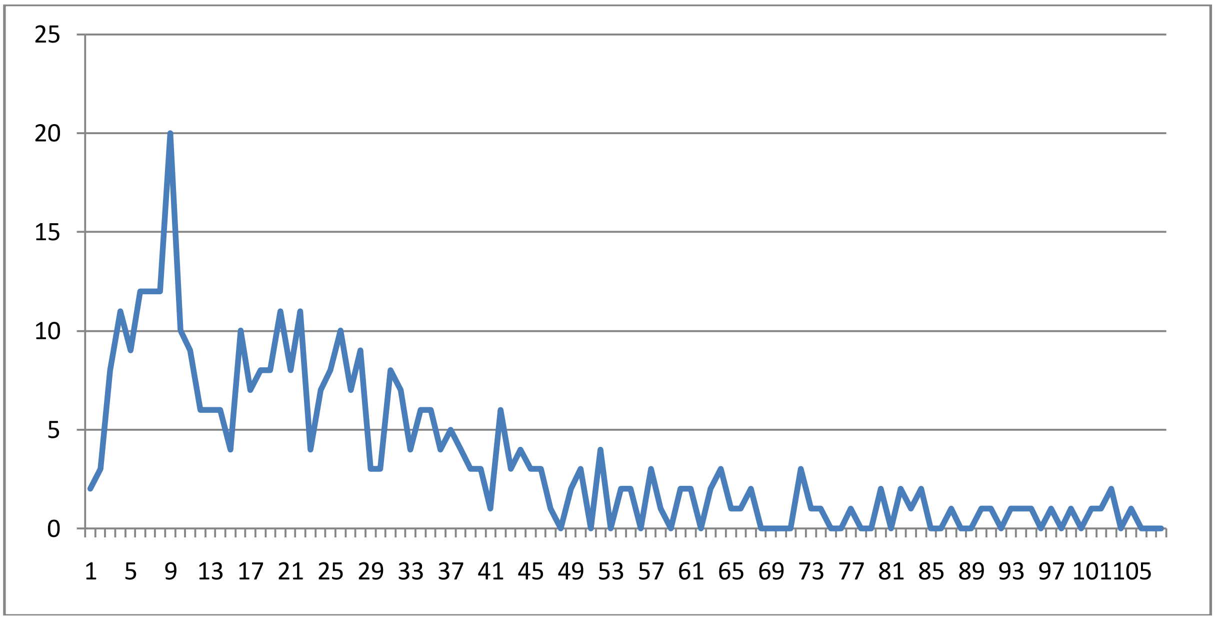

Chart 5.3 illustrates a typical frequency function. The x-axis is representing the size of the order, expressed in pallets, and the y-axis indicates the number of occasions.

The frequency function in *chart 5.3* is based on daily ordering (confirmed order) and there are more examples of frequency functions presented in a*ppendix 3*. It is desirable to match the demand structure with a statistical method to ease safety stock calculation. Based on the appearance of *chart 5.3* and the ones in *appendix 3* the demand structure is not likely to conform to the most common statistical model; normal distribution. On the contrary it appears to be more corresponding to gamma distribution. A visual test of compatibleness with different statistical models for one of the products most resembling normal distribution is presented in *chart 5.4* below.

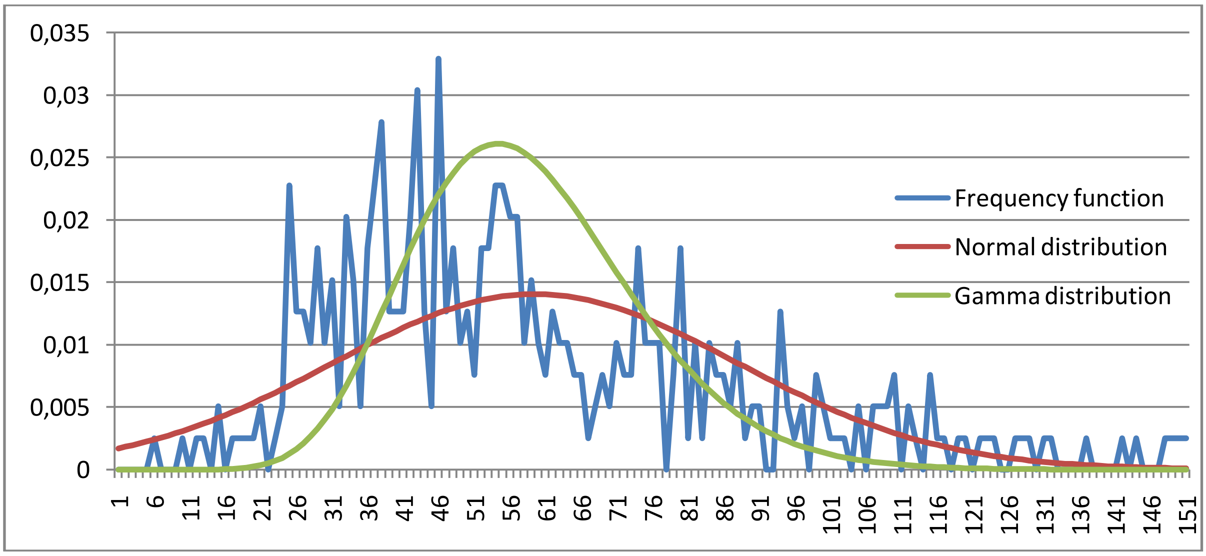

Chart 5.4 illustrates the compatibleness for the frequency function compared to gamma distribution and normal distribution.

As *chart 5.4* illustrates the normal distribution does resemble the frequency function fairly well. Sadly the relatively large standard deviation make the normal distribution account negative values which makes its usefulness limited. In contrast the gamma distribution coincides quite well with the frequency function.

However if the demand structure of a products is to be adapted to a statistical method for safety stock calculation it must take the lead time into consideration i.e. the daily demand has to be converted into demand during lead time. If the lead time is comprised into the calculation the frequency function will alter its appearance. The daily order intake is relatively fluctuating which is shown by the large standard deviations which are mostly the size of the arithmetic mean or greater. The weekly order intake on the other hand is less pendulous which is further illustrated in t*able 5.11* below.

Article	1	2	3	4	5	6	7	8	9	10
	Pallet demand per day									
Mean	38,6	23,3	52,5	63,0	58,6	238,0	171,9	40,4	27,5	62,2
STD	61,9	27,3	51,2	66,3	71,5	326,0	240,4	35,2	35,3	81,7
	Pallet demand per week									
Mean	270	163	368	441	410	1666	1203	283	193	435
STD	161	86	171	187	183	1032	777	108	112	219

Table 5.11 illustrates daily and weekly order intake expressed in pallets for respectively timeframe.

As illustrated in *table 5.11* the standard deviation is reduced to be smaller than the mean for all products. Since the average lead time for a product is longer than a week the standard deviations will be reduced even more. However the standard deviations are still too large to apply the normal distribution. Although with longer lead times and more values accounted the frequency function will conform to normal distribution according to the central limit theorem. In conformity with *chart 5.4* a visual test of the compatibleness of the frequency function and gamma distribution is presented in *chart 5.5* below.

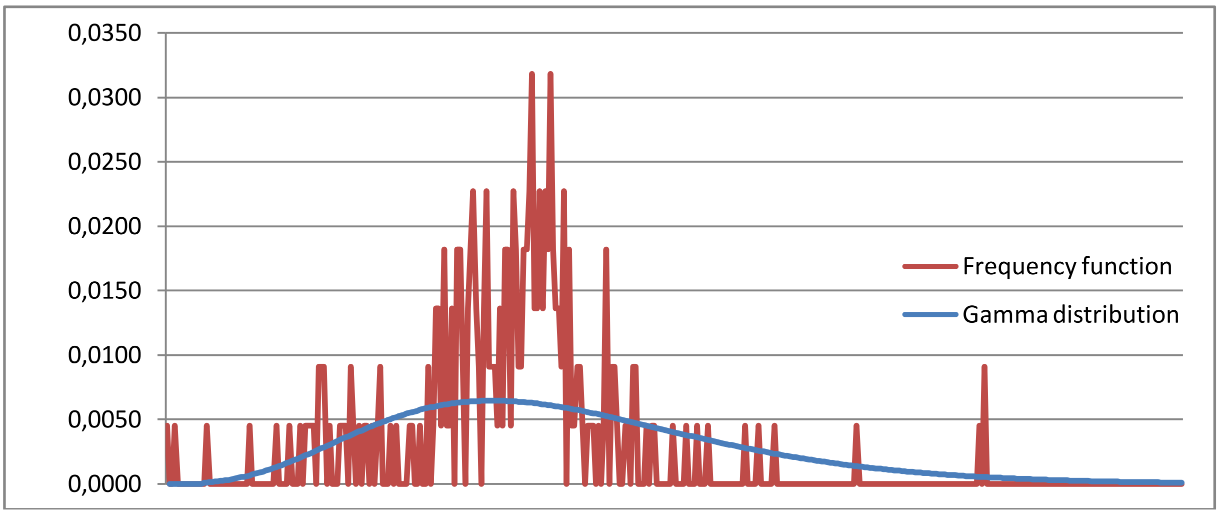

Chart 5.5 illustrates the compatibleness for the frequency function compared to gamma distribution.

Additional charts of compatibleness for the gamma distribution are presented in *appendix 4*. As the charts illustrate the gamma distribution corresponds rather well with the current demand structure which makes it suitable as base for safety stock calculation.

Remarkable in all charts is the impact of large orders which has a flattening effect on all gamma distribution curves. Without these extreme peak values the gamma distribution would be even more compatible with the frequency function and the frequency function itself would be more coherent.

5.5 Safety stocks

The safety stock policy with a fixed level of two weeks demand practiced in logistics centres presently is a somewhat coarse method to calculate safety stocks. The method is in essence an estimation and hence it is joint with an amount of uncertainty. Even worse is the use of two weeks production since it does not have to be any correlation between production and the customer's demand. When calculating the demand for two weeks no consideration is taken to the actual demand structure. To not reflect upon the demand structure is likely to have a negative effect on capital deployment and service levels. An illustrative example based on actual orders is presented in *example 5.1* below.

Example 5.1

Consider a product with few orders per year and with some large quantities.

All orders for a product during an entire year									
90	3900	60	30	270	90	270	270	300	60
1120	1372	28	196	224	924	476	2436	504	1848

The table above illustrates the total order intake during a year. Each number in the table illustrates an order. The orders are in chronological order (read from top left). The annual demand for this product will be 14468 and divided on 46 weeks the weekly demand will be 315 pieces. Two weeks demand would then be 630 pieces. Since this product is ordered only 20 times per year is probable that the safety stock is the only stock for this product. If the safety stock level is compared to the ordered values 7 orders will be missed due to insufficient goods. For this particular product the orders sizes of 28, 196, 224, 924, 476, and 2436 were all placed within the same week make another order missing its delivery date. If the safety stock would be based on two weeks production, based on an average batch of 2000 pieces, instead of two weeks demand it is probable that all orders would be delivered in time but the inventory carrying costs would be far too high.

If the demand structure in *example 5.1* would have been 200 orders per year instead of 20 the safety stock would serve its purpose much better. The suggested change in @-cap, to use M3 Serv1 calculation, is therefore positive since the method comprises the demand structure. However, the M3 safety stock calculation is based on a demand structure that conforms to normal distribution which is not the case for many of Swedwood's products.

The biggest problem when choosing on a model for safety stock calculation is what to base it upon. To use the measurement of service classes defined by IKEA is not especially tempting. The measurement does not isolate the supplier performance, consequently Swedwood could have delivered all orders received and the service level still may be less than 100 percent. To base safety stock calculation on the delivery security measurement is not an eligible solution either. The delivery security measurement does only comprise the time aspect of dispatches which makes it hard to use to manage safety stocks. As a result there is no IKEA defined measurement suitable to base safety stock calculations on.

However, the definition of service level could with ease be modified to be an alternative. Today the service level is measured only in the stores but the same measuring could take place between IKEA and Swedwood but it should than be formulated as: How many ordered goods versus how much was dispatched. This definition could be interpreted as an orderline fill rate service which resembles the Serv2 definition. The Serv2 definition would then be suitable to base safety stock calculations upon rather than the current use of Serv1.

As described in the previous chapter the demand structure for most Swedwood products conform quite well to gamma distribution. Hence safety stock calculations are probably most accurate when combing gamma distribution with the Serv2 definition.

As described in the empiric chapter the service levels are in general maintained quite well. However since the measurement is carried out in IKEA stores it does not have to reflect upon Swedwood's actual performance as supplier. It is plausible to believe that goals of service levels are reached thanks to large buffers through the entire supply chain. Without buffers the delivery security of roughly 80 percent would have resulted in shortages thus leading to reduced service levels.

5.6 Comparison between Poland West, Älmhult, and Tibro

The production layout and setup is in all factories more or less the same where the biggest differences are the size and the level of automation in production lines. More interestingly is the variation in inventory control principals and setup. The most complex setup is the one in Tibro. The inventory control principals applied in Tibro is quite sophisticated and advanced. The accuracy of this inventory control system outperforms all the other existing inventory control system within the Swedwood group. However, the system has an indisputable disadvantage and it is the high level of manual interference. Of course in the Tibro case it is not a problem since the number of articles is very small which makes the manual work required manageable. This setup would be close to impossible to apply to both Älmhult and Poland West since the article range is much greater. Another disadvantage with the Tibro inventory control system is also related to the manual work. The performance of the inventory control system depends largely on the skills of the planner although it must be stressed that a good planner is likely to outperform a standard setup computer based system by far. The setup in Älmhult is in part the very opposite to Tibro because of the extensive use of computer aid in production planning. The usage of computer to ease production planning is very positive but there is also a risk with such an approach. If there are problems with inventory control the system will suggest on measures to counter the problems but it will not provide the answer to what caused the problem hence such a system must be used with caution. The Poland West inventory control system is somewhere in between the other two, not manual and it does not use complex add-on programs.

The planning horizon for the three production units is different. The use of different planning horizons is probably much affected by the delivery structure. Both Poland West and Tibro have a significant share of their deliveries carried out via direct deliveries. Direct deliveries are at a constant high level in its demand whilst orders to regional warehouses are more seldom but with peaks. As a consequence of this planning horizons for Tibro and Poland West are shorter. The long planning horizon in Älmhult entails a smooth production but much of the agility is lost. However, the order pattern for regional warehouses is easier to predict hence it does not have to be negative for Swedwood Älmhult.

When it comes to inventory turn-over rate the production units are much alike. Poland West has the highest rate with its 24 times per year. With 48 production weeks this means that the inventory is turned over once every two weeks. Älmhult has the lowest turn-over rate of the three units but still it manages to turn-over its inventory approximately once every 3.5 weeks. Considering the high turn-over rate these production units will not be able to make any significant reductions in capital deployment. The planning horizons combined with the size of safety stocks make it hard to boost the inventory turn-over rate further.

When it comes to safety stocks the units have different setups in conformity with other aspects. Tibro is the only unit following the company standard in determining their safety stocks, strangely the use of two weeks demand coincide almost perfectly with the safety stock levels imposed by the @-cap suggested method used in Poland West. The Älmhult method of partly using an ABC-classification to determine safety stocks is a positive initiative but it should also be combined with a model comprising demand structure e.g. Serv1. Of the three units the model used by Poland West is the one most adapted to the current demand structure. However, all production units would benefit to use more sophisticated methods for safety stock calculation. The production unit in Tibro would serve excellent as a starting point to test a new model because of its limited range of products which would enable meticulous surveillance.

6 Conclusions and recommendations

In this chapter the conclusions drawn from the preceding analysis are presented. The chapter also contains suggestions on how inventory management could be slightly enhanced. Finally the chapter will address some issues that Swedwood ought to investigate further.

6.1 Conclusions

One of the biggest issues the Swedwood's logistics centres face is the lack of a unanimous classification model. The current situation where classification might not be used at all is most likely to have a negative effect on customer service since no differentiation of products is made. By not having a policy on classification, prioritization in inventory control will be hard. The risk of making incorrect decisions is high since there is only the IKEA service class to base the decision on. The prioritization will therefore depend largely on the planners experience and knowledge of the product demand.

To solely use the IKEA service classes as a classification is not an eligible solution to the problem. The use of IKEA service classes to classify products will only be useful if it is combined with an additional criterion. The most suitable criterion to use is frequency because of two reasons. Firstly, frequency is used in some logistics centres even though it is not for inventory control. Secondly, frequency reflects more on the demand structure than its main alternative volume. However, if a production unit has the majority of products in the same service class it is best to apply a dual criterion ABC-classification with frequency and volume.

By combining the two criterions frequency and the IKEA service class, the logistics centre and the production would get a joint platform for planning. By giving production and logistics centres a common platform for classification both units will get a better overview of which products to prioritize.

With the adoption of a dual criterion ABC-classification, the EOQ-model should be investigated further. The use of EOQ batch sizes has the potential to reduce costs and enhance capacity utilization.

The current inventory control system used at Swedwood is a hybrid of two inventory control principals, the time-phased order point system and the periodic ordering system. This hybrid system works less satisfying than what either one of the systems would have done by itself. Hence Swedwood is recommended to refine its current setup to be either a time-phased order point system or a periodic ordering system. Both inventory control systems have advantages; the periodic ordering is not depending on the IKEA forecast and the time-phased order point system minimizes capital employed. Considering the current situation, the time-phased order point is to prefer because of its abilities to reduce capital deployment. Of course, the time-phased order point system is depending on the IKEA forecast which is more uncertain than actual orders. However, by using a time-phased order point system fully, consistency in planning will be improved.

However, if the time-phased order point system is to be used the current routines for MPS planning must be reformed. The use of one fix planning point has to be altered to a planning period with numerous planning points. A planning period with several planning points would enable the MPS to be gradually filled with orders. An extended planning period has a few advantages compared to a fixed planning point. The main advantages are that it becomes easier to sequence production and production can be levelled off between periods.

A time-phased order point system would benefit from accounting undershoots in planning. If the undershoots are used in the ATP check, DO-proposals would be generated earlier and service towards customers will be enhanced. Planning would also benefit since the lead time will be elongated.

To change the inventory control system to be a pure time-phased order point system entails the MPS to be entirely based upon forecasts. The quality of the forecast used at present, the IKEA forecast, is quite uneven. For some products the forecast is satisfying but for others it is too imprecise. To apply the forecasting technique of exponential smoothing will lower some of the fluctuations in forecasts hence Swedwood ought to apply this technique to forecasts.

The quality of forecasts is affected by numerous parameters. Unreliable delivery performance may cause the forecast quality to deteriorate but it can not be the only explanation. The change in delivery structure is another possible explanation. Order cancellations are also likely to have an influence on forecast quality. These factors concern both Swedwood and IKEA and the parties have a joint responsibility for the quality of forecasts. This master thesis has only suggested on a few parameters that potentially could have an effect on forecast quality and it is likely that more parameters are affecting forecast quality.

Forecasts are one of the most influencing parameters for inventory control. Another parameter with a large influence is the demand structure. The current demand structure is characterized by two quite different order types. Despite the fact that J-orders are much larger than B-orders, B-orders have a larger impact on inventory control. The high number of requested orders on Mondays is in large part cause peaks in the work load in logistics centres. The order requests for Mondays correspond approximately to the request for three days if the demand were to be evenly distributed over the week. If the IKEA stores were to place order requests for the weekends as well the work in logistics centres would be a lot easier. It is advised that Swedwood investigate if it would be possible for the IKEA stores to request orders even on weekends.

The majority of days during a year have a higher fraction of small orders (confirmed orders) than large orders, i.e. the typical daily confirmed volume of orders is small. There are, however, a not insignificant number of large orders as well. These large orders can be educed to orders from regional warehouses and Mondays. These orders cause problems in form of peaks in work load and an irregularity in the goods flow. The weekly orders confirmed is fairly stable which ought to enable the daily rate of confirmed orders to be so as well.

The actual demand structure converted into frequency functions should be the main input to safety stock calculations. The current policy of setting the safety stock level at two weeks demand is likely to have a negative effect on service towards IKEA.

When studying the frequency function on daily basis, the frequency appears to coincide quite well with gamma distribution. However, when accounting the lead time the normal distribution tends to be an alternative. Sadly, with the current lead time the normal distribution is of limited use because of its inability to exclude negative demand. In contrast the gamma distribution works quite well regardless of the lead time. Consequently, the safety stock calculations used should be based on gamma distribution. However, if the lead time is elongated it is possible to use normal distribution also. This in turn leads to the conclusion that lead time has a large impact on safety stocks and inventory control. With lead time, this master thesis has identified three parameters as crucial for inventory control; the IKEA forecasts, the demand structure, and the lead time.

The three production units included as illustrative examples are much alike in terms of production. There are differences in inventory control though. The inventory control model used in Tibro is the best one but unfortunately it can only be used with very small production ranges. For most other units the inventory control setup in Älmhult, with a change in planning horizon, is to prefer. Currently, Swedwood Poland West manages their safety stocks best even though Tibro is coincidentally the same. Based on the high turn-over rate in inventories, these units will not be able to make any significant reductions in capital employed in inventories.

6.2 Recommendations

It is recommended that Swedwood implements the use of the suggested double criterions ABC-classification model as soon as possible. Units that already have initiated the @-cap project are suitable to be first since the both criterions are already in use there although separately and for other reasons. Changing the current classification to the dual criterions ABC-classification is probably the most important change suggested in this master thesis.

The current Swedwood setup of a time-phased order point system needs some refinement. Swedwood should review if it is possible to extend the current time frame for planning. A fix planning point is not eligible when using a time-phased order point system. The planning process should therefore be revised within the near future.

Swedwood ought to consider undershoots in their ATP check. The undershoots have a large impact on service towards customers wherefore it is important to acknowledge them. The current ATP could likely be re-programmed to account undershoots without any major difficulties. To included undershoots in the ATP is believed to be fairly comprehensible, hence this measure is one that could be executed within a near future.

As previously mentioned the IKEA forecast is an important input to the inventory control system at Swedwood. The current situation with uneven forecasts is causing problems for Swedwood, this in form of difficulties to keep a levelled production. Swedwood and IKEA should therefore launch a project aimed at identify what parameters affect the quality of forecasts. Another desirable outcome would be to determine the key success factors for those products with good quality forecasts. Furthermore, the possibility to transfer the key success factors onto other products should be investigated by the project.

The current safety stock policy is in need of a change. A safety stock calculation based on gamma distribution in combination with the Serv2 definition would serve the Swedwood logistics centres well. However, it is not realistic for Swedwood to change to this model at present. The model represents state of the art inventory control whereas Swedwood currently is on the other side of the scale. The transition to more elaborate calculation model should approached step-by-step. The first step is to use the @-cap suggested method, Serv1. The second step is to change into calculations based on Serv2 with normal distribution. The final step is to use Serv2 with gamma distribution. Swedwood may be ready to use the more elaborate model in 2-3 years.

6.3 Future studies

During this study much of the time has been spent on understanding the interface between Swedwood and IKEA. It seems that a lot of the problems Swedwood face is due to lack of understanding the IKEA way of work. The same goes for IKEA, a lot of their problems are due insufficient knowledge of Swedwood's production. Hence these problems can be educed to inadequate communication between the two parties. These companies are quintessentially the same wherefore communication should not be a problem. Hence it would be interesting to investigate how better communication modes could enhance the both companies performance.

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Appendix 1 - Questions to managers on production units

Inventory related questions

What is your main market?

Do you have any main products?

How many articles do you keep in stock?

What is your maximum storage capacity?

Is the storage capacity sufficient?

Do you use any type of racks or such to store goods?

How many pallets do you have in stock at the moment?

What is your inventory turn-over rate?

Do you have any models to classify your products, e.g. ABC-classification?

If yes is the model practiced and what parameters are used?

Do you have any specific models for inventory control?

How are these models used to facilitate the work with inventory control?

Are the models operated by M3 or are they operated manually?

Do you feel that these models are sufficient to run inventory and production smoothly?

If not, what are the models lacking in terms of ability?

What is the single most influencing factor on your inventory control?

What is your lead time from receiving an order to dispatch?

How do your deliveries take place, many direct deliveries, deliveries to regional warehouses, or other?

How is the safety stock level determined?

Do you use any models for safety stock calculation?

How often do you revise safety stock levels?

Do you make any difference between products of different safety classes, i.e. S0, S1 etc?

Which measures do you use to measure service levels?

What demands does your customer impose on you?

How well are these demands met?

How do you measure delivery security?

What demands do your customers have on delivery security?

How well are these demands met?

Production related questions

How is production carried out, Line-production, work-shop based etc.?

How many shifts does your production run?

How big is an average batch?

How would you describe your production when it comes to efficiency?

Do you believe that the production is a limiting factor when it comes to satisfying customer needs?

Do the products you manufacture have long setup times?

Appendix 2 - Forecasts versus orders

The highlighted cells mark the forecast used as foundation to plan the MPS.

SPI	42	43	44	45	46	47	48	49	50	51
41	4180	4970	**4670**	4510	3910	3510	3300	3010	2680	3420
42		4000	3720	**3440**	3210	3550	3420	2990	2770	3840
43			9510	3420	**3400**	3600	3620	3030	2850	3720
44				11400	5650	**6120**	6290	5100	3260	5250
45					11050	6260	**6210**	5060	3310	5390
46						4710	6060	**5930**	4000	5640
47							5460	3920	**3840**	4640
48								1560	1080	**1550**
49									0	0
Order			2530	2940	1240	2380	490	2430	3920	

This product is discontinued and has been since SPI 41, i.e. it is to be removed from the range of products.

SPI	42	43	44	45	46	47	48	49	50	51
41	2748	3270	**2712**	2520	2370	2532	2382	2598	2418	2820
42		2760	3192	**2316**	2466	2442	2532	2442	2532	2850
43			2526	3072	**2226**	2394	2382	2622	2322	2940
44				2610	2898	**2274**	2562	2394	2448	2802
45					2106	3018	**2172**	2388	2268	2940
46						2082	2520	**1986**	1788	2478
47							2040	1548	**858**	1188
48								1146	1104	**1032**
49									324	660
Order			1980	3420	2766	1272	774	900	402	

SPI	42	43	44	45	46	47	48	49	50	51
41	1638	1824	**1482**	1452	1428	1332	1476	1296	1356	1548
42		1596	1668	**1392**	1356	1380	1410	1308	1368	1596
43			1374	1584	**1404**	1392	1386	1332	1398	1608
44				1464	1590	**1380**	1380	1350	1368	1554
45					1356	1608	**1362**	1332	1260	1698
46						1296	1398	**1056**	1194	1290
47							1170	636	**468**	474
48								558	624	**378**
49									162	324
Order			1296	1218	1530	2172	1128	1686	318	

SPI	42	43	44	45	46	47	48	49	50	51
41	10640	9672	**8408**	7560	6944	7520	6960	6824	6192	7672
42		9968	9152	**7488**	7296	7480	6928	6368	6344	7168
43			9336	7880	**7064**	7584	6920	6544	6336	7464
44				9328	7368	**7352**	7008	6368	6288	7264
45					8696	7384	**6888**	6336	6024	7288
46						9112	7416	**6248**	6456	7464
47							8840	6968	**6648**	7592
48								8992	7288	**8216**
49									7576	7504
Order			6896	8704	9392	8712	10240	8344	8392	

SPI	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**
41	13832	12730	**10792**	10070	11096	10754	12388	11742	11286	13134
42		12768	12198	**10146**	10868	11096	12198	11552	11134	13096
43			13224	12274	**10741**	11020	11956	11856	11120	11514
44				16138	16264	**12870**	12122	12290	11818	13155
45					14972	14934	**13034**	13414	12464	16188
46						15580	14326	**13870**	11932	14896
47							15770	14516	**11514**	13756
48								14744	12274	**13262**
49									15580	15086
Order			10754	15656	10982	15618	13566	16112	21964	

SPI	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**
41	31293	35511	**28044**	23997	26277	26733	28614	25821	23370	26733
42		30723	36651	**24168**	27702	24681	29925	24795	26106	26676
43			28728	33288	**24738**	24054	26049	25194	22173	30096
44				28671	33744	**25992**	23826	23883	24510	27816
45					27759	36366	**25308**	25080	21831	29925
46						28272	38076	**23826**	22743	27987
47							27873	37278	**21603**	28158
48								26904	34884	**28671**
49									24282	39045
Order			17784	27417	16473	36993	25365	22194	54720	

SPI	42	43	44	45	46	47	48	49	50	51
41	2420	4150	**3460**	3050	3190	3280	3340	3130	2740	3630
42		3290	4240	**2770**	3040	3220	3320	2860	2760	3060
43			3230	3320	**3010**	3390	3230	3220	2780	3490
44				3940	5370	**4860**	4210	4020	3750	4040
45					2700	3710	**3820**	4360	3660	4840
46						2940	3750	**3450**	3790	5040
47							3090	5330	**5290**	5280
48								3640	5410	**5060**
49									4170	4910
Order			3500	3970	3620	4660	3550	3350	7790	

SPI	42	43	44	45	46	47	48	49	50	51
41	352	847	**825**	880	737	770	825	627	825	908
42		319	616	**858**	726	649	704	649	748	768
43			374	743	**610**	725	699	681	737	570
44				343	484	**636**	688	471	650	653
45					308	572	**539**	605	693	484
46						407	506	**671**	528	704
47							396	583	**572**	627
48								330	539	**594**
49									187	286
Order			143	506	231	385	418	759	1188	

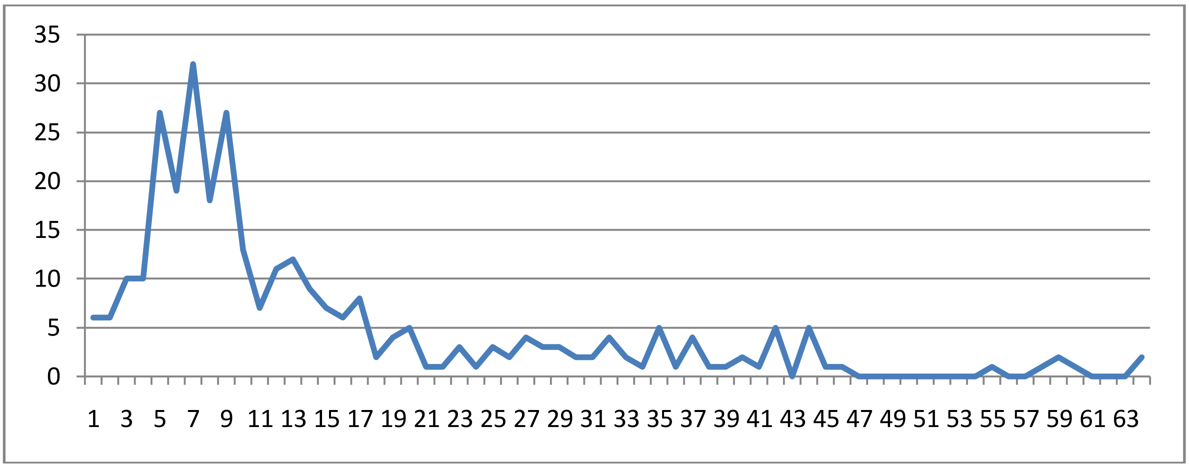
SPI	42	43	44	45	46	47	48	49	50	51
41	4032	3960	**3912**	4200	3840	4056	4032	3888	3432	4368
42		3720	3648	**3384**	3672	4152	5328	3840	3408	4152
43			3024	3432	**3360**	4296	4872	4128	3144	3504
44				3720	3336	**4200**	4488	3744	2736	3720
45					3528	3912	**4416**	3816	2976	3528
46						2496	2712	**2256**	2544	2160
47							2808	1296	**1272**	1032
48								1848	1128	**792**
49										24
Order			1944	2856	2520	3624	3592	3384	384	

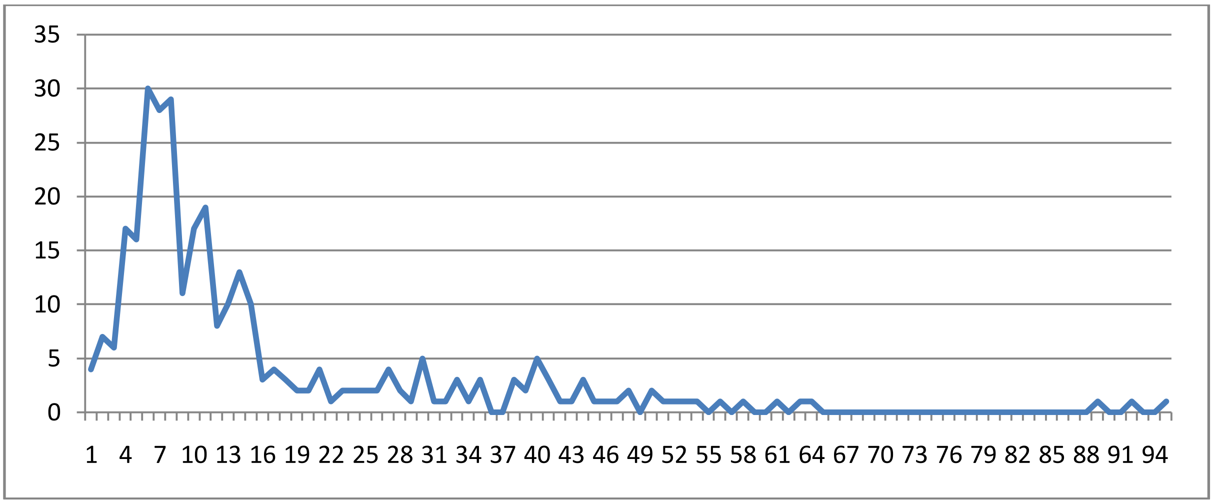
SPI	42	43	44	45	46	47	48	49	50	51
41	2784	2975	**3288**	3071	3072	2975	4728	2975	3959	3401
42		2711	2544	**2831**	3048	3119	3888	3119	3798	3504
43			2232	2857	**3727**	2994	3948	3806	3371	3189
44				2361	2945	**3423**	4040	3396	3427	3129
45					2973	2780	**4100**	3233	3460	3103
46						2040	2280	**1968**	1999	1531
47							2088	1200	**1498**	840
48								1392	1377	**1015**
49									24	72
Order			1968	2832	3576	3192	1608	984	168	

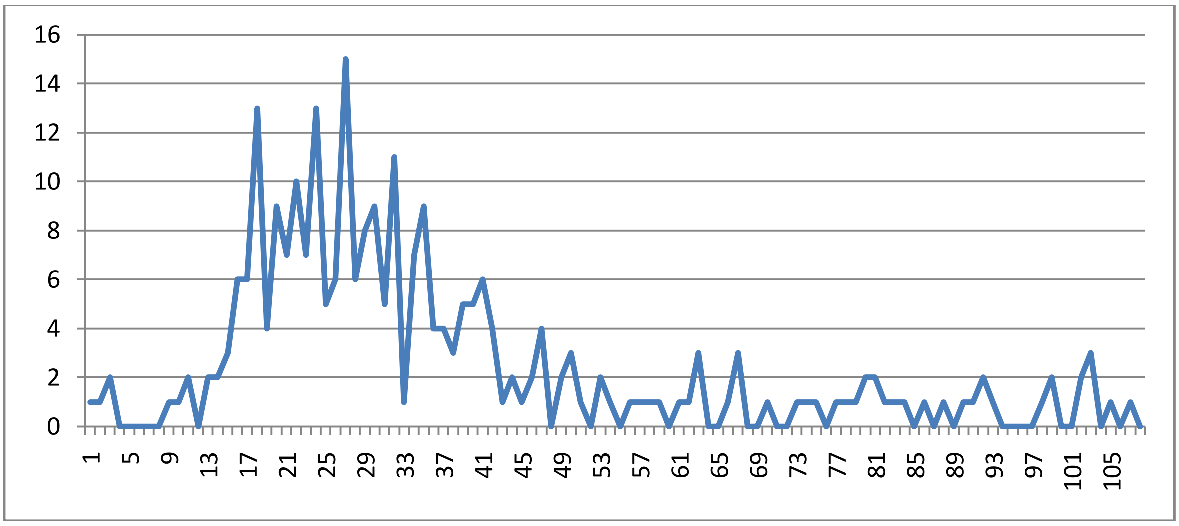
This product has a cancellation rate of 35 percent during these 9 weeks

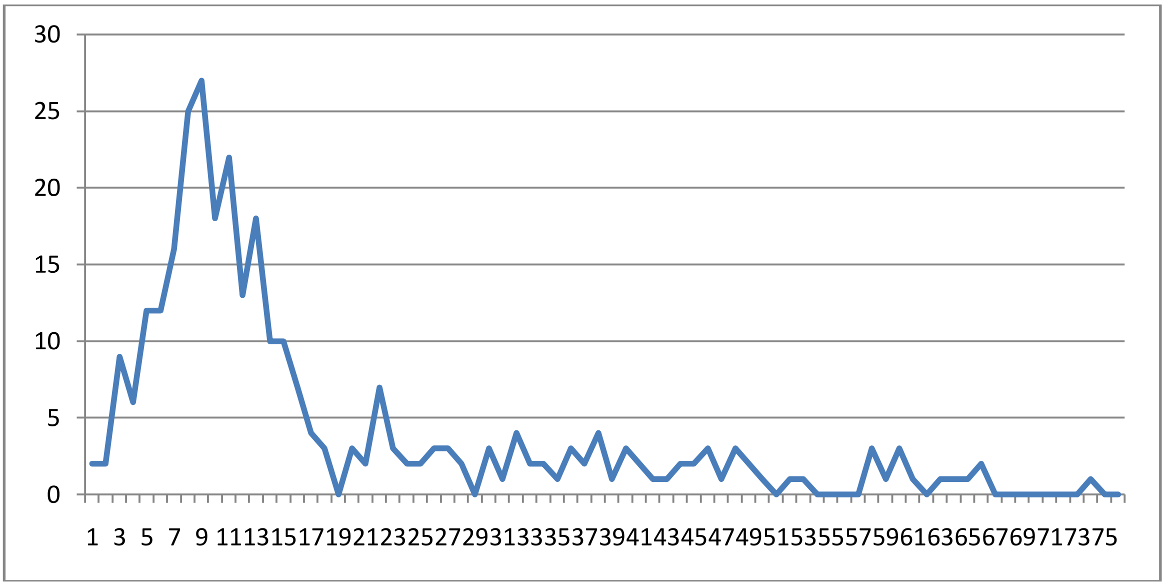
Appendix 3- Frequency functions of daily demand

The frequency functions are based on statistics from Tibro and Poland West FY 2008-2009.





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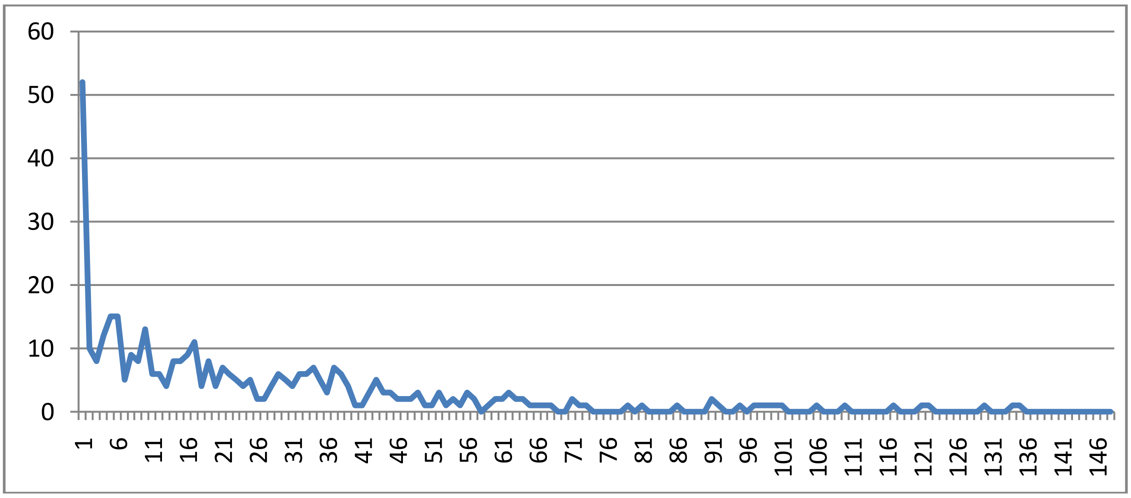
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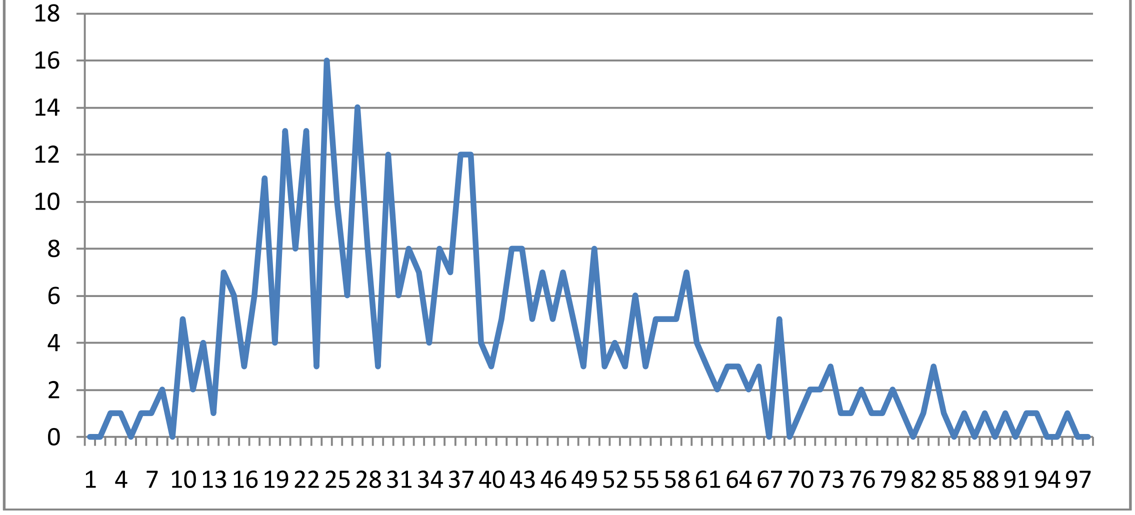
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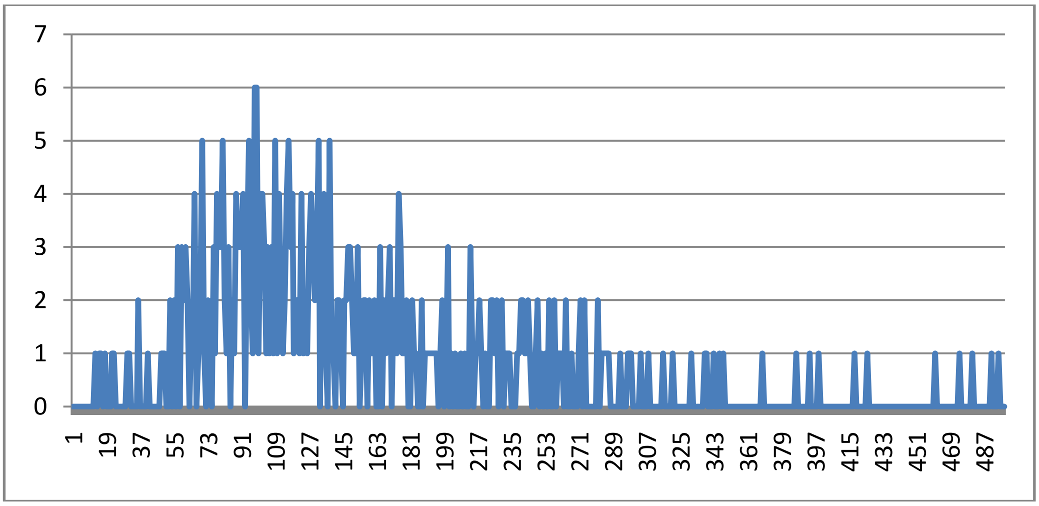
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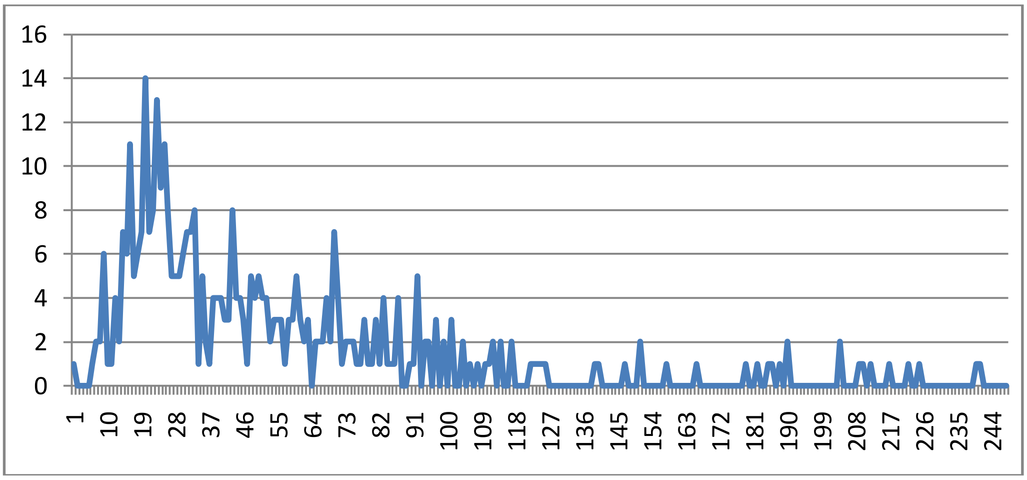
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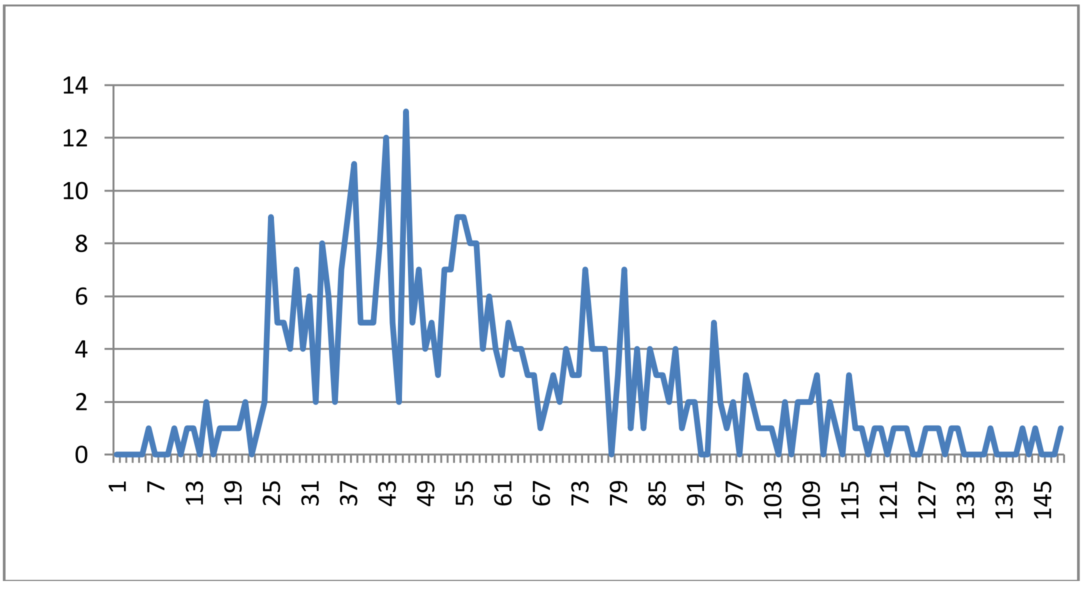
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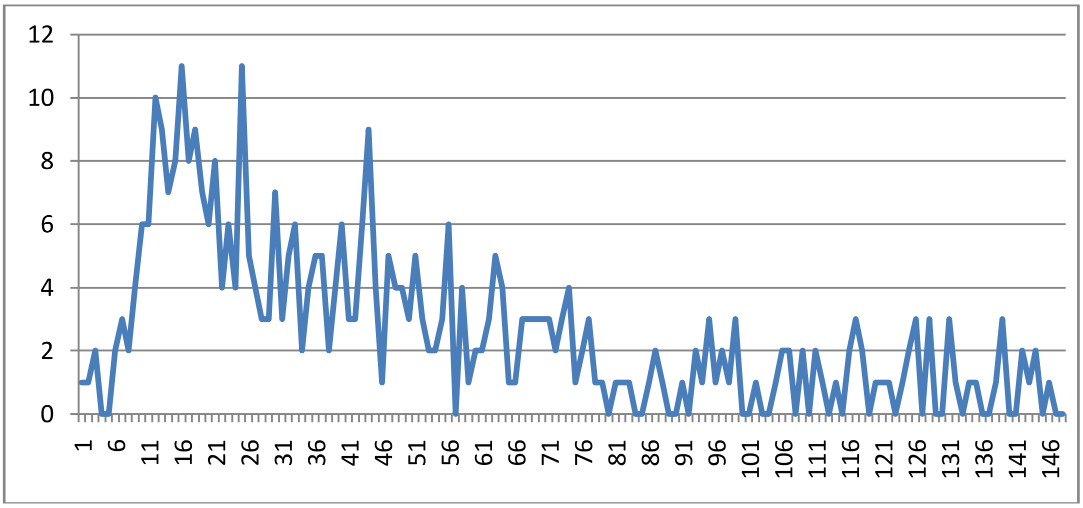
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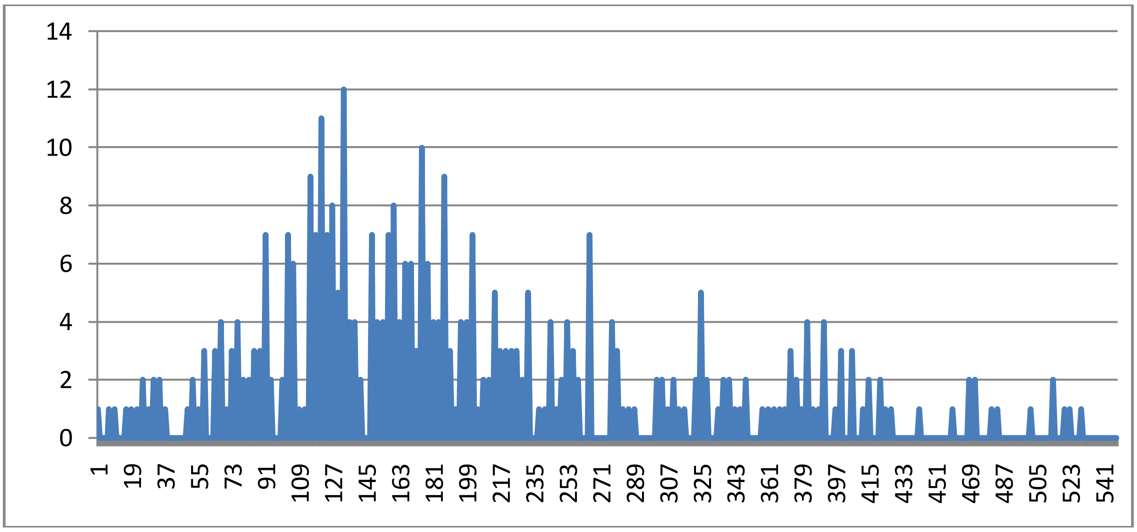
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146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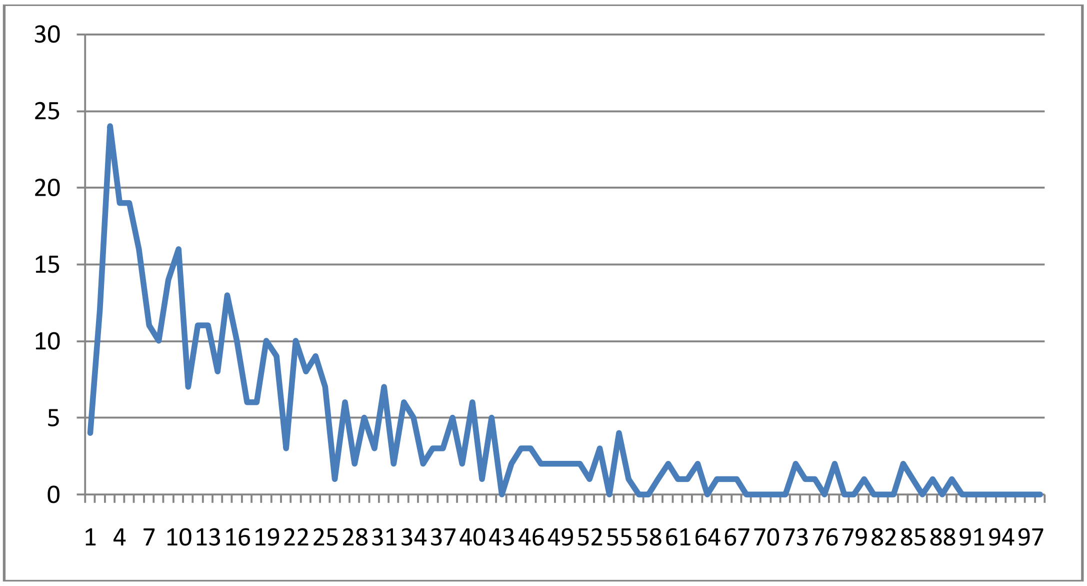
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10
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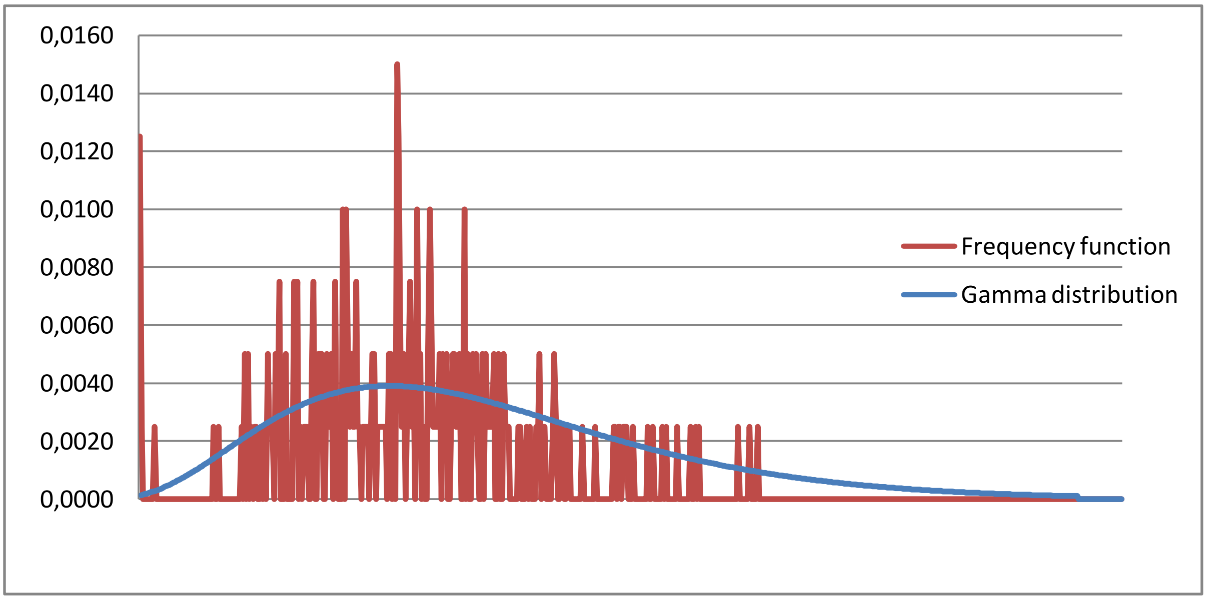
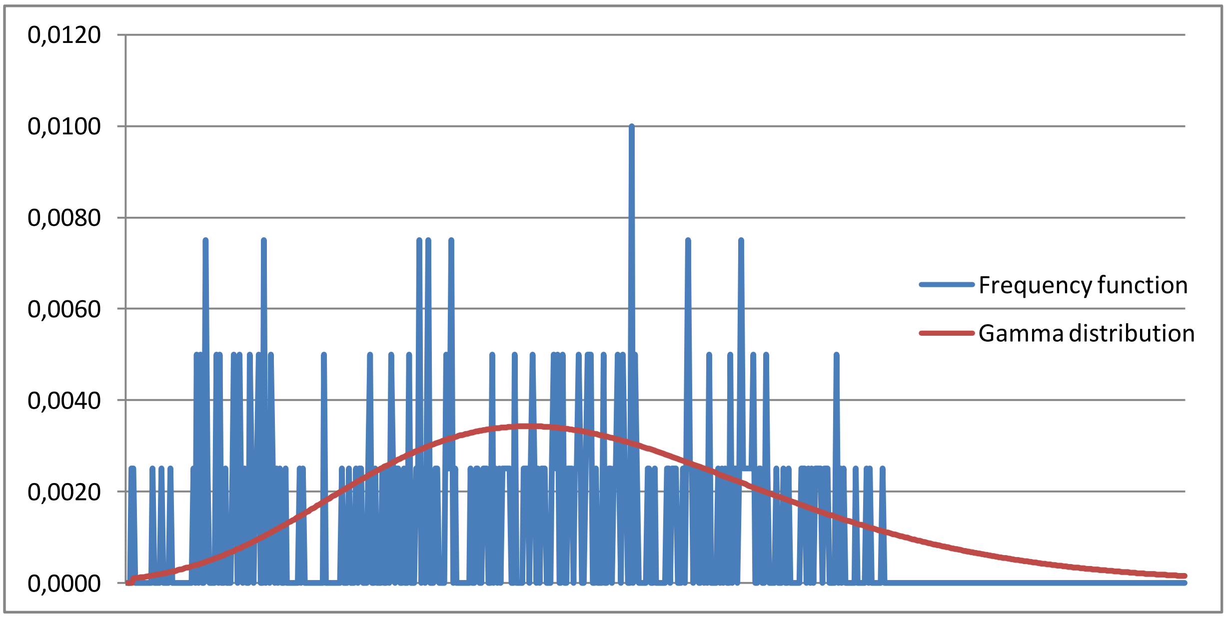
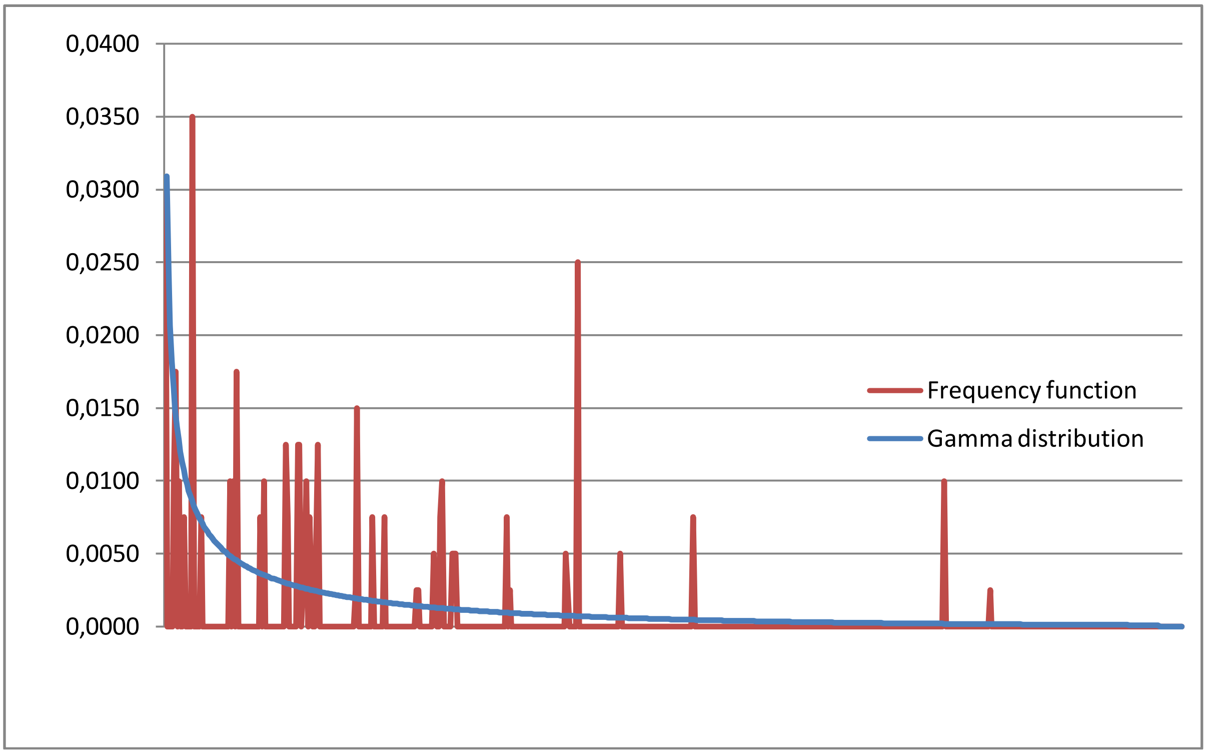
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70 73 76 79 82 85 88 91 94 97

Appendix 4 – Frequency functions and Gamma distribution diagrams

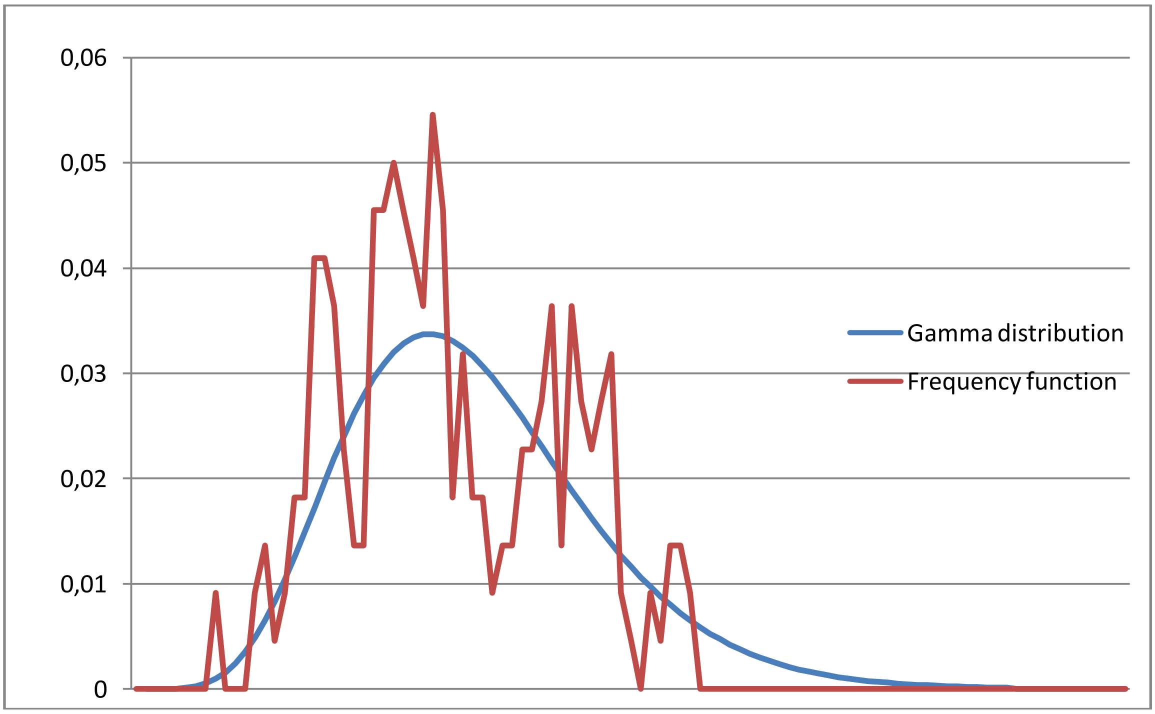
The frequency function in the graphs illustrates the frequency and size of the demand for pallets per week, the gamma distribution illustrates the theoretical frequency for weekly pallet demand. All graphs are limited to only illustrate the area of interest, practically all graphs have peaks but these are well outside the boundaries of the graphs.

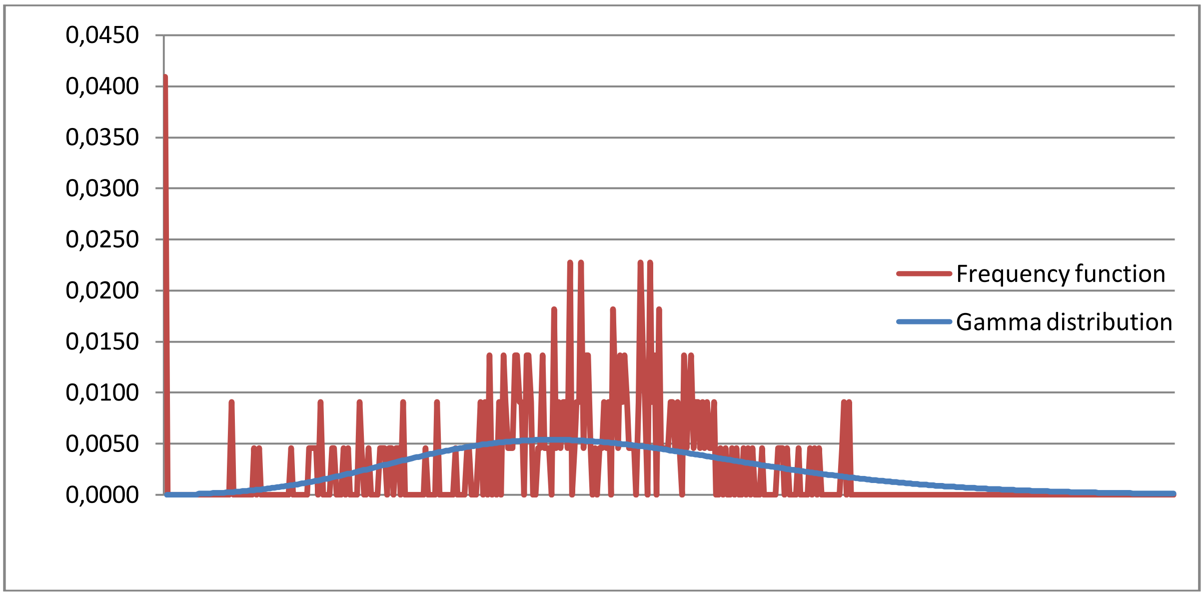






The initial peak of the frequency function has been reduced from its original start value to make the diagram easier to read. The frequency function has its start value at naught, i.e. no pallets per week. The value of the peak was 0.21 which means every one week out of five does not deliver any pallets at all.

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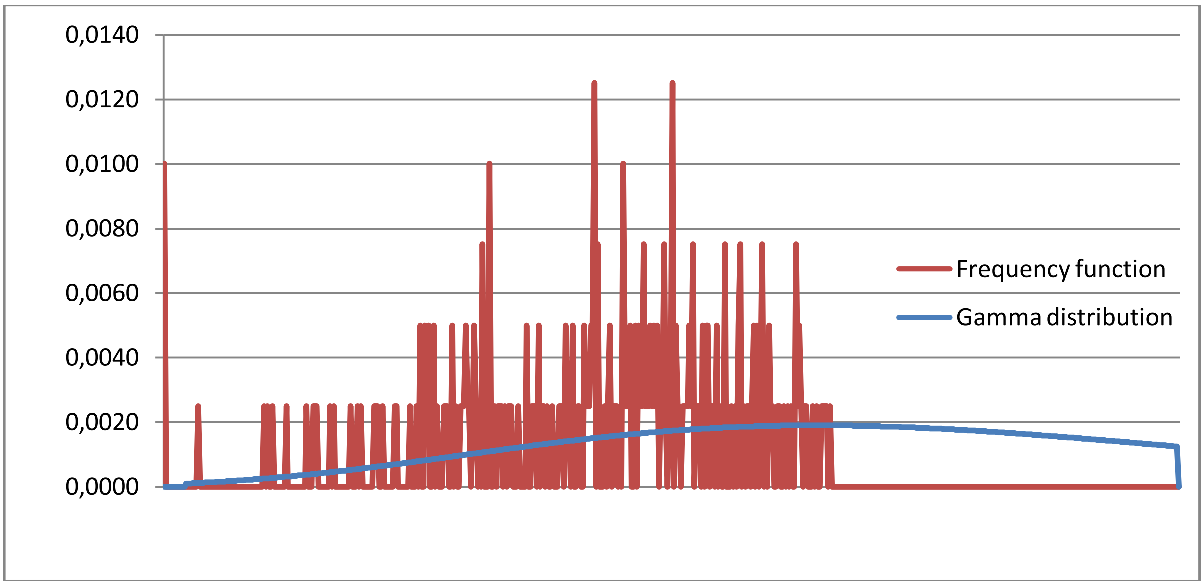
Frequency function
Gamma distribution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Frequency function
Gamma distribution