Increasing the inventory turnover rate focusing on order quantities and safety buffers

- conducted at UniCarriers Manufacturing Sweden AB

Master of Science Thesis in the Master Degree Program Supply Chain Management

LABAN CRAMÉR
MIKAEL LAKSO

Department of Technology Management and Economics
Division of Logistics and Transportation
CHALMERS UNIVERSITY OF TECHNOLOGY
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PETER OLSSON

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ERIK PALMQUIST

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Technical report no. E2014:046
Department of Technology Management and Economics
Division of Logistics and Transportation
Chalmers University of Technology
SE-412 96 Göteborg Sweden
Telephone + 46 (0)31-772 1000

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ABSTRACT

The purpose of this thesis has been to understand how to improve the inventory turnover rate for an MTO-company in a purchasing and logistics perspective. With emphasis on lot sizing methods and different approaches of how to calibrate safety buffers, the inventory turnover rate measure's denominator: the value of average inventory has been in focus. The research was built around UniCarriers Manufacturing Sweden AB's purchasing and logistics division and its operations in the beginning of 2014.

The inventory turnover rate is a key performance indicator within procurement for most manufacturing companies at the same time as procurement activities get increasingly important. The insights from the research are thus believed to be valuable for any MTO-company managing a large number of purchase articles.

The report is divided into a literature framework, a part describing empirical findings at UniCarriers Manufacturing Sweden AB and an analysis part that elaborates on the theoretical and empirical findings. The report ends with a discussion and conclusion part where final recommendations are presented.

By introducing economic order quantity to generate article specific order quantities, each article's average inventory would according to simulations be reduced. As the other core area for improvement, a redefined ABC-matrix that generates fill rates to determine safety buffers has been introduced. Volume value is an inventory policy measure that is directly connected to the inventory turnover rate. By only using the volume value, the service level towards production would increase and the employed capital in inventory would be reduced in the long term. The suggested proposals concerning the two core areas, lot sizing and safety buffer, do not constitute the full improvement potential. Therefore other factors were investigated to find additional improvement potentials.

Key concepts: ABC classification, inventory turnover rate, lot sizing, safety stock, safety time, service levels

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- To all other employees at UniCarriers Manufacturing Sweden AB – Thank you for your interest in our work.

DEFINITIONS

Key definitions are stated and explained in the following chapter as support for the reader. Below definitions are written in italic letters throughout the report.

- *Actual order quantity:* The actual order quantity refers to the order quantity that is ordered from the supplier, which is a multiple of the MRP-system order quantity.

- *Control parameter:* Parameters used to manage and measure inventory performance, e.g. service levels, inventory turnover rate and value of inventory.

- *Fix safety stock:* The safety stock used for class C articles, which corresponds to eight percent of the article's annual consumption.

- *Forecast based articles*: Articles that are not customer order specific, have a forecasted annual consumption and purchased in batches. These are the focal articles in this thesis.

- *Inventory policy measures:* Ways to categorise articles into an ABC-matrix, e.g. classes based on volume value, consumption or supplier.

- *MPC-system*: Manufacturing planning and control-system, in UniCarriers Manufacturing Sweden AB's case delivered by Multi.

- *MPC-system order quantity:* The MPC-system order quantity refers to the order quantity used as input in the MPC-system.

- *Procurement cost:* The procurement cost refers to the costs for order placement, direct purchasing, inbound transportation and for holding inventory.

- *Procurement process:* The procurement process refers to following steps: order placement, inbound transportation, initial inventory handling and stocking of inbound articles.

- *Purchasing price:* The price paid to the supplier for an article.

- *Safety buffer:* Refers to both safety time and safety stock.

- *Standard price:* Corresponds to the purchasing price multiplied by a standard price factor.

- *Theoretical order quantit*y: The theoretical order quantity refers to the calculated order quantity from the ABC-matrix.

- *Total lead-time:* The total lead-time is equal to the supplier lead-time and transportation time.

FIGURES AND TABLES

To easily navigate in the material, lists of all used figures and tables are presented in this chapter. The lists are sorted in order of appearance in the report.

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TABLE OF CONTENTS

1 INTRODUCTION

The introduction chapter aims to describe the subject's relevance and to highlight the purpose of the thesis. Considered limitations are also presented to clearly state the scope of the work.

1.1 Background

Until recently, procurement activities were just considered to be a necessary part of any manufacturing company but usually not to have significant importance. Procurement divisions have historically often had to fight to be accepted as value-adding parts of organisations. Times are changing and procurement activities are now more and more acknowledged as an integral part of any company's competitiveness. Procurement activities tend to get more attention from management as their understanding of the potential to realise cost savings and added value in the area increases. Today, most companies are thus aware of the importance of having an efficient procurement function, but still many struggle in their efforts to utilize its full potential. A major reason that procurement is considered to be increasingly important is found in most global companies' profit and loss accounts, exposing the well-stated trend that material costs as share of the total is growing continuously, and thus each percent of cost savings get greater.

In light of the intensified focus on procurement activities, the Boston Consulting Group arranged a roundtable with 30 European CPOs in 2008. The gathering resulted in a published report, stating that the number one challenge within procurement was to secure the right knowledge base in the organisation by training and development of the work force (Gocke, 2008). Employees' knowledge is important to be able to apply theories and literature to realise most potential within procurement. Theories such as ABC classification of articles, Wilson's formula for economic order quantities and different service level measurements are examples from the literature aiming to facilitate and improve procurement, but they simultaneously require knowledge to make a good fit to each company. Other top priority challenges mentioned at the CPO roundtable were collaboration and cross-functionality to avoid sub-optimisation within organisations. Most companies are considered to face these challenges including the focal company in this thesis: UniCarriers Manufacturing Sweden AB (UCMSWE), a mid-sized company located in Mölnlycke.

UCMSWE is a producer of forklifts with around 240 employees working at the production site. With a global supplier base and thousands of articles kept in inventory, its procurement activities are both important and challenging. The purchased material corresponds to a considerable part of the company's total costs. Benton (2009) states that *procurement costs* in general vary between 50 and 80 percent of the total costs and that assembling companies usually are found in the upper part on the interval. Within its procurement activities, UCMSWE is especially interested in its inventory turnover rate of *forecast based articles* where the potential for improvements is believed to exist. By increasing the knowledge about inventory management theories regarding lot sizing and *safety buffers*, the company hopes to increase its inventory turnover rate.

1.2 Purpose

The purpose is to increase the inventory turnover rate by primarily focusing on lot sizing and *safety buffers*. This is done with consideration to both service levels towards production and *procurement costs*.

1.3 Problem analysis

UCMSWE has been used as reference, but the discussed problems are not company-specific and the ambition has been to accomplish results also valuable for other similar companies. In order to reach the purpose of this thesis, three research questions have been stated:

RQ1: How does UCMSWE manage procurement of forecast based articles today?
The first research question considers how UCMSWE is working with procurement of *forecast based articles* today. The topic is a prerequisite to be able to answer the other two research questions.

RQ2: Is UCMSWE using relevant inventory policy measures in its procurement process?
The second research question concerns how and when to categorise *forecast based articles* into classes. It questions when to purchase articles based on unique article characteristics and when to aggregate articles into classes.

RQ3: How can lot sizing and safety buffers be used to increase the inventory turnover rate?
The third research question asks how to increase the inventory turnover rate by looking at *safety buffers* and lot sizes for UCMSWE's *forecast based articles*.

1.4 Scope and limitations

The empirical findings at UCMSWE only consider *forecast based articles*. The company purchases the other articles in too small volumes or too infrequently to be analysed in this context.

In a supply chain context, the report covers activities from when UCMSWE purchases articles to when the same articles are picked out from the inbound inventory to be used in production. All further upstream and downstream activities are excluded.

1.5 Report outline

The report consists of six main chapters, starting with the current introduction and followed by a methodology chapter. The thesis deals with relevant theory and empirical findings before going into an analysis of both theoretical and empirical data.

Further there is a chapter for discussion and conclusion, which also includes explicit recommendations to UCMSWE. Short descriptions of the chapters follow:

Methodology

The methodology is described in chapter two and explains the research methods used in this thesis. The methods used for the theory and empirical findings are both inductive and deductive approaches.

Theoretical framework

The third chapter deals with the theoretical framework based on a literature study of relevant areas built around the UCMSWE business case and a theoretical model created early in the process.

Empirical findings

The fourth chapter describes the empirical findings at UCMSWE, focusing on how the company works with procurement. The empirical findings follow the same model as the theoretical framework to focus the findings on the main scope.

Analysis

The fifth chapter is divided into three analysis parts dealing with: order quantities, *safety buffers* and complementary factors influencing the inventory turnover rate.

Discussion and conclusion

The chapter discusses the findings from the analysis, their potential and feasibility. Final recommendations to UCMSWE about how to improve its inventory turnover rate are also given.

2 METHODOLOGY

The methodology chapter describes how the work has been conducted. It starts with a discussion about the overall research strategy and continues with the undertaken work process and used methods for data collection. Methodology reflections about chosen methodologies and their reliability and validity round off the chapter.

2.1 Research strategy

The research strategy defines a framework where suitable ways of work progress and analysis are discussed. According to Kovacs and Spens (2006), a research approach is deductive, inductive or abductive. While a deductive research approach focuses on theory collection and comparison, an inductive research approach aims to build up a theoretical framework around a real case. Abductive research approaches are rarely used and focuses on building up totally new hypotheses (Eriksson & Wiedersheim, 1991).

The work has been applied to a real business case, where specific observations at UCMSWE constituted the core problem statement. A broader scope of theory was built around the real business case to back up the analysis, all according to an inductive research strategy. Theories have also been compared according to a deductive research strategy.

2.2 Work Process

The work process started with a planning report to establish the purpose, scope and research questions for this thesis. After confirming the proposed purpose, scope and research questions with the tutors at both Chalmers University of Technology and UCMSWE, the work process was divided into three main parts: a literature study, empirical findings and an analysis part, see figure 1.

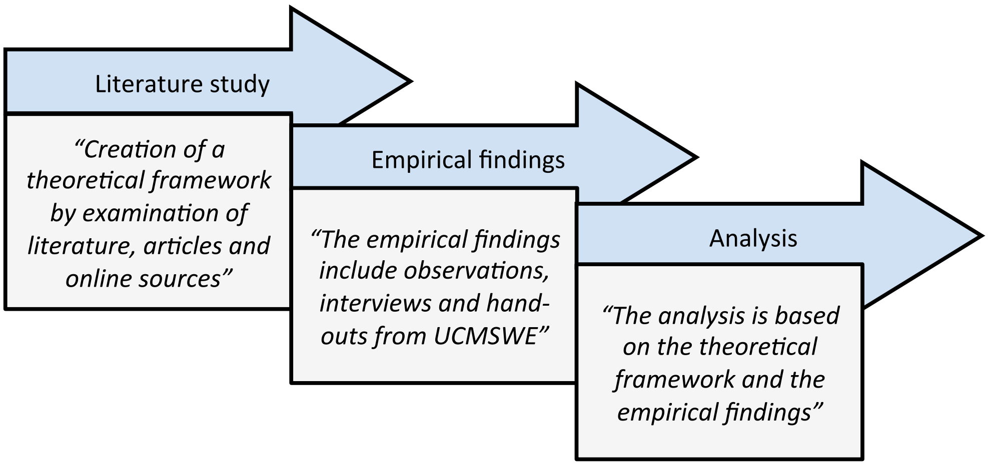

Figure 1. The work process was divided into three areas: the literature study, empirical findings and analysis

The first phase, the literature study, began as soon as the planning report was completed. A model was created to structure the research of literature. The model focuses on the inventory turnover rate, directly linked to the purpose, where parameters related to the inventory turnover rate also were researched. The theoretical framework was conducted from relevant literature, mainly from student literature, articles and online sources. The same model was used to structure the collection of empirical findings.

The empirical findings phase started right after the literature study was initiated and the two parts were thereafter performed in parallel. The empirical findings were conducted through frequent observations, interviews and collected hand-outs at UCMSWE's production site in Mölnlycke. The interviews focused on the department of purchasing and logistics to get knowledge of daily routines and how the manufacturing planning and control-system (*MPC-system)* works. During the work a computer connected to the *MPC-system* was available to give further chances to do research. The inventory turnover rate and inventory levels have been in focus during the entire empirical process and all findings were mapped in excel to create a holistic view of all data collected. In the latter part of the empirical research, some efforts were given to broaden the scope to gain an even deeper understanding of factors influencing the inventory level. In the end of the empirical findings, the model used to structure the theoretical and empirical research was once again brought up with modifications.

In the analysis phase, the theoretical framework was used as a guideline to approach the empirical findings. The data found in the empirical findings facilitated simulations to visualise the *procurement process*. The analysis is divided into three parts: the two main parts concerning lot sizing and *safety buffers* as well as a part about identified complementary factors that are influencing the inventory level. The analysis ends up in recommendations to UCMSWE.

The work resulted in a final report published online. The thesis was also communicated with two presentations, one at Chalmers University of Technology as well as one at UCMSWE's production site in Mölnlycke.

2.3 Data collection

Data can be collected with several different approaches. Befring (1994) divides data into two categories: primary data and secondary data. Primary data refers to interviews, observations and surveys while secondary data refers to information gathered from sources other than its origin. Ejvegård (2003) stresses the importance of a comprehensive literature study that covers written material from articles, books, reports and other publications and emphasis the importance of using references. This should be done to facilitate for both the authors and readers to use and control conducted reference material.

Both primary and secondary data has been used to write the empirical and theoretical parts. The primary data was collected from observations and interviews at UCMSWE's production site in Mölnlycke. Secondary data was primarily collected to support the literature study and was found in literature, articles and online. The methodology of how data from literature, interviews, observations and other hands-out was collected is described below.

Literature study

Halvorsen (1992) stresses the importance of creating a research purpose and scope before starting a literature study, to avoid spending an unnecessary amount of time on the research. Rumsey (2008) means there are two key points when researching literature: the subject must be clear and a well defined purpose and scope. On the other hand, Lekvall and Wahlbin (2001) argue that the literature study should be conducted before the problem and purpose is fully formulated.

To satisfy the purpose of this thesis, a model has been created to navigate in the researched literature. The model is focused on the inventory turnover rate measure with its surrounding factors. The model was created to narrow the scope and to create a focus of the research in the right direction. The main source of literature has been study material from the Supply Chain Management master at Chalmers University of Technology and Chalmers library's database. Databases such as Google scholar and other online sources have also been used for the collection of secondary data to the literate study.

Interviews

Interviews can be divided into the two categories: quantitative and qualitative interviews (Hartman, 2004). Quantitative interviews aim to get short and direct answers often expressed in numbers or other direct answers. Qualitative interviews are held with open questions where the interviewee has the opportunity to give comprehensive answers. Qualitative questions should therefore not involve any leading questions. Interviews could also be categories as structured and unstructured interviews, where unstructured interviews are similar to regular conversations and structured interviews are more formal and predetermined (Gillham, 2000). Gillham (2000) also mentions semi-structured interviews where there are predefined questions but where the interviewer is able to ask follow up questions. Hartman (2004) underlines the importance of taking notes and recording both prior and during conducted interviews.

Conducted interviews in this thesis have been both semi-structured and unstructured. The interviews have also been mainly qualitative to get as much information as possible from different employees' perspectives. Both authors of this report have been present during all interviews to take notes and to mitigate the risk of missing or misinterpreting information. During the interviews, tools such as Microsoft Office, whiteboards, sound recordings and pictures have been used to facilitate the knowledge sharing. A meeting journal was used to keep track of conducted interviews and key findings. The interviewed employees at UCMSWE have been working with purchasing, material planning, business controlling, logistics and manufacturing. Interviews have mainly been conducted to give understanding of daily routines, work processes and UCMSWE's *MPC-system*.

Observations

Observations are an important part of data collection since it brings knowledge about real behaviour and are in comparison with interviews a more reliable data source (Aaker et al., 2001). Observations reflect what actually happen while interviews reflect the interviewee's perspective of what has happened (Bell, 2000). Nevertheless, observed information can be misinterpreted by the observers (Hartman, 2004).

The observations have all been conducted at UCMSWE's production site in Mölnlycke and have been performed in parallel with interviews. The focus has been to gain knowledge about the daily routines and to understand the *MPC-system*. The observations have both been accompanied with the tutors at UCMSWE but also without any supervision.

Hand-outs

The last source of data is information that has not been published for public use. This information is referred to as hand-outs and primarily covers information about how UCMSWE on a high level works with its ABC classification.

2.4 Structuring the data

The quantitative data has been processed in excel and organised into a master document. This has facilitated the overview and structure of the gathered data to enable simulations. The main part of this information has been gathered directly from UCMSWE's *MPC-system*, but some information has been added from theory, hand-outs and interviews. The master excel document includes the following information for each article, expressed in table 1.

Table 1. The areas of information that has been collected about the forecast based articles.

Article information	
Annual consumption	Order quantity
Article price	Safety stock
Consumption statistics	Supplier information
Lead-times	Volume values
Order frequency	

Annual consumption

There are two kinds of annual consumptions in this report: one is the forecasted annual consumption, which always has a time horizon of one year and updated quarterly. The other annual consumption is the actual consumption data during 2013, which has been calculated from 2013's transaction data collected from the *MPC-system*. The annual consumption is one of the keystones in the calculation of the volume value. Furthermore the annual consumption could be used to calculate measures like order quantity and order frequency.

Article price

Two price measures have been collected. The *purchasing price* is the price that is agreed upon together with the suppliers. This price is used together with consumption when calculating the volume value. The other price measure, *standard price,* is the *purchasing price* with a surcharge called the standard price factor. The standard price factor consists of a transportation component and an administration and material component. The *standard price* is used to calculate the value of the inventory and therefore also a component in the inventory turnover rate.

Consumption statistics

From the 2013's transaction data some statistical measures have been calculated. The transaction data is the actual inbound deliveries and transactions out from the inventory. The most important statistics are the *forecast based articles'* average consumptions per day, the number of outgoing transactions per year and the articles' demand variations during lead-time. These measures are primarily used to find a relationship between safety time and safety stock and to dimension *safety buffers* from service levels. The transaction data itself is also important for simulations of the inventory levels during 2013.

Lead-times

The lead-times collected are both the supplier lead-times (the time from the when suppliers get the orders until the orders are shipped) and the transportation times. These two times together constitute the *total lead-time* and are used when calculating *safety buffers* from a considered service level.

Order frequency

There are three different order frequencies collected. The first one is given directly from the ABC-matrix. The second order frequency collected is the order frequency calculated from the order quantity in the *MPC-system*. The last order frequency is computed from the 2013's transactions data and is the actual number of times each article has had an inbound delivery.

Order Quantity

There are three different order quantities collected. The first one is given directly from the ABC-matrix, referred to as the *theoretical order quantity*. The second order quantity collected is the order quantity in the *MPC-system*, referred to as the *MPC-system order quantity*. The third order quantity is referred to as the *actual order quantity* and measures the real size of inbound deliveries. The order quantity is an important measurement for the strategic purchasers and has a direct relation to the inventory level. The order quantity is also used to calculate the average inventory level.

Safety Stock
The collected safety stock data comes both from the *MPC-system* and from stated safety stock levels in the ABC-matrix. The safety stock is an important parameter to understand the total inventory.

Supplier Information
The information gathered about UCMSWE's suppliers concern supplier-article relations, how many days of transportation each supplier needs and also the number of delivery days per week that they are allowed to use. The supplier information is important to understand what articles that are shipped long distances but also to understand how important a supplier is according to its amount of articles and volume value.

Volume Value
The volume value is the product of the *purchasing price* and the annual consumption for an article. The information is used to decide in what category an article should be allocated and is also used to understand the importance of an article and its supplier. The volume value is the basis to understand the importance of an article and how much capital employed it results in.

2.5 Methodology Reflection

Interviews are by nature subjective, providing information that has to be dealt with critically (Ejvegård, 2003). Ejvegård (2003) also argues that observations are in risk of being subjective and thus have to be viewed critically. Davidson and Patel (2003) further states the importance of high quality data, which heavily depends on the degree of uncertainty of the material collected.

By aiming to use multiple information sources throughout all parts of the data collection, the ambition has been to present the theoretical framework and the empirical findings in an objective manner. In some areas single source information has been used, which may have resulted in lower quality of collected data.

3 THEORETICAL FRAMEWORK

To understand how UCMSWE can apply theory about inventory management to improve its inventory turnover rate, a theoretical framework has been established. The inventory turnover rate model presented in figure 2 constitutes the structure for the following chapters in the theoretical discussion. Areas precedent to a company's inventory turnover rate, including ABC classification of articles, lot sizing, service levels and *safety buffers* are discussed to understand each area's relationship to the inventory turnover rate measure. Complementary factors that influence the inventory turnover rate has also been discussed.

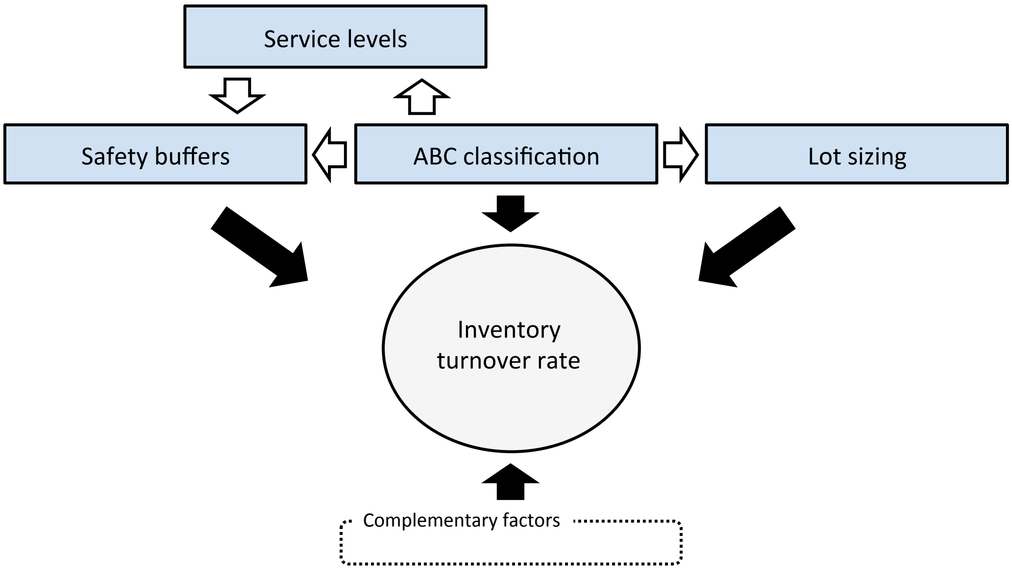

Figure 2. The inventory turnover rate model that structures the theoretical framework.

3.1 Inventory management

Inventory management is defined as the branch of business management concerning planning and control of inventories, with responsibility to maintain a desired level of inventory for specific articles or products. The primarily aim of inventory management is to serve the customer at a reasonable cost to the own business (Toomey, 2000).

Inventory management is important to be able to plan the inventory levels to cover for demand fluctuations. Safety stocks and safety times are two ways to generate these *safety buffers* to handle described uncertainties. Inventory management is used to handle the trade-off between the inventory level and the service level that the inventory performs downstream the supply chain (Spratt, 2006). The described trade-off is presented in figure 3 and shows possible mismatches between current states and target performances (Spratt, 2006). For example, if the same *safety buffer* size is used for several articles, ones with less volatile demand and lead-time may receive higher service level than targeted (Mattsson, 2014d). Consequently high volatility articles may receive a lower service level than targeted.

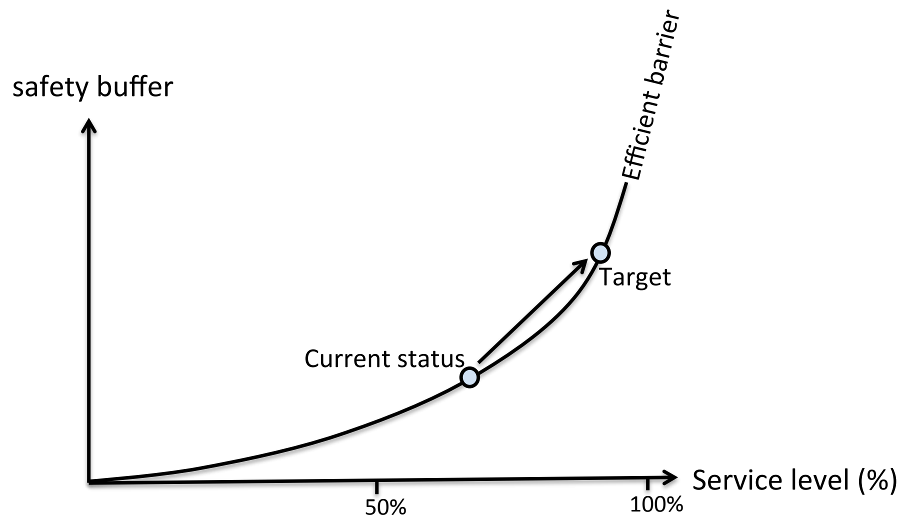

Figure 3. The graph is showing the trade-off between service level and safety buffer (Spratt, 2006).

Lot size consideration is also central within inventory management. While larger order quantities may result in price discounts and less resources needed to manage the ordering process, smaller order quantities result in lower average inventory. As seen in figure 4**,** the largest inventory level is the sum of the safety stock and order quantity and the lowest inventory level equals the *safety buffer.*

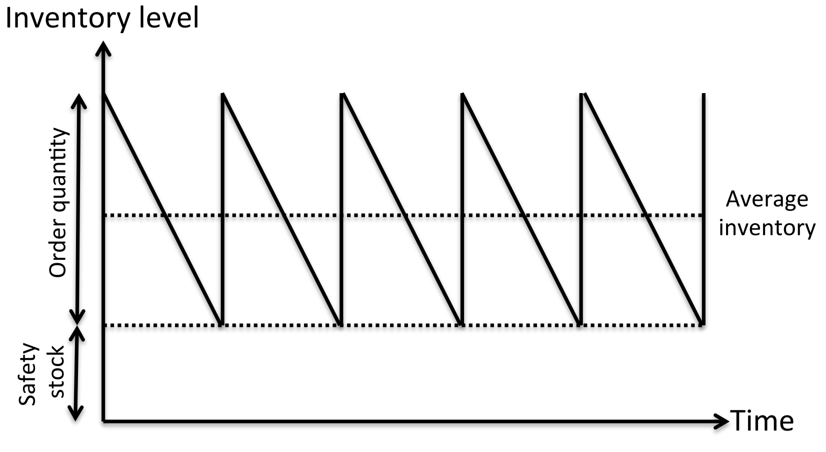

Figure 4. An inventory curve going between the safety buffer level and the safety buffer plus order quantity level (Toomey, 2000).

With a constant picking flow from the inventory, the average inventory level is thus equal to the safety stock plus half of the order quantity, which is seen in equation 1 (Toomey, 2000).

$$Average\ inventory = \frac{Order\ quantity}{2} + Safety\ stock\ (1)$$

To understand how well an inventory is managed, *control parameters* are used. Most *control parameters* evaluate the performance in terms of money, not quantity or time.

The most commonly used *control parameter* is the inventory turnover rate (Gossard, 2007). A discussion about the inventory turnover rate is presented in the next chapter.

3.2 Inventory turnover rate

The inventory turnover rate is, as Gossard (2007) emphasises, an important measure of how well an inventory is managed and looks at how many times an inventory is replaced over a period of time. The higher inventory turnover rate, the better is a company's liquidity (Muller, 2011). Equation 2 expresses how to calculate the inventory turnover rate.

$$Inventory\ turnover\ rate = \frac{Cost\ of\ articles\ consumed}{Value\ of\ average\ inventory} \quad (2)$$

The formula looks straightforward to use, but there are several aspects to consider before doing any calculations of an inventory's turnover rate (Muller, 2011). When the inventory turnover rate is used for business controlling purposes, focus is on how many articles that are sold, while a company's production unit tends to focus on inventory turnover rate in terms of how many articles that are actually taken out of the inventory. Additionally, for the period of time used to calculate the average inventory, ingoing and outgoing inventory level have to be in parity to get a valid indication about the real inventory turnover rate (Muller, 2011).

Another consideration when measuring the inventory turnover rate is how to value articles with dynamic *purchasing prices*. To be able to get a correct inventory turnover rate, consistency is important in this aspect. Two frequently used methods to value an inventory are first-in, first-out (FIFO) and last-in, first-out (LIFO). Using FIFO, a company assumes the price for consuming an article to be equal to the price paid for the first article put in inventory. In the example in figure 5, the price used for inventory valuation would be 5 SEK with FIFO. With LIFO, the most recently added article's price is used to valuate the inventory, corresponding to 30 SEK in figure 5. Another method is to use a weighted-average method where all historical *purchasing prices* are considered to calculate the average inventory value (Averkamp, 2014).

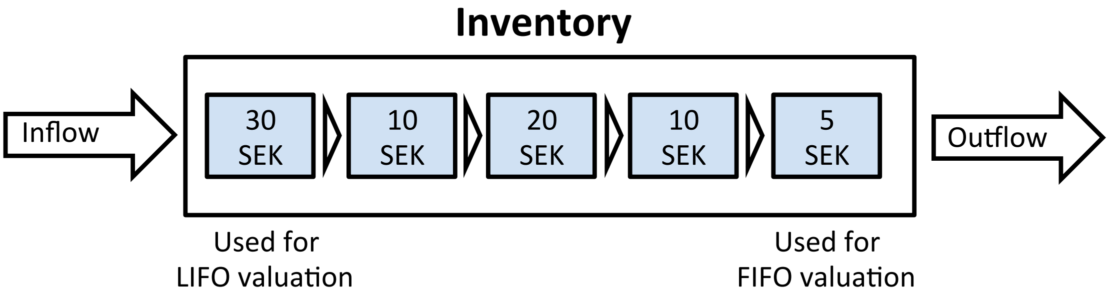

Figure 5. There are different approaches of inventory valuation when purchasing prices are dynamic, including FIFO, LIFO and weighted average methods (Averkamp, 2014).

3.3 ABC classification

ABC classification is an effective inventory management tool since most modern production companies have thousands of inventory articles to handle (Hadad & Keren, 2013). To have separate *control parameters* (service level measures, weeks on hand etc.) for each article is therefore not economically feasible, nor a practical approach (Hadad & Keren, 2013). To cope with this inventory management issue, many companies use article grouping where each specific class contains articles that are defined according to its relative importance in terms of chosen *inventory policy measures* (Hadad & Keren, 2013). When grouping articles, it is essential to take a starting point in the organisation's specific characteristics since the requirements can vary substantially from company to company. The same goes when an organisation is about to change or update its inventory management (Axsäter, 2006). Therefore, this chapter elaborates on issues companies have to consider when working with ABC classification in their inventory management.

3.3.1 Structure of ABC classification

The ABC classification, initially developed by General Electrics in the 1950s, normally starts by ranking considered inventory articles by importance (Millstein et al., 2014). The rule of thumb is that a small number of articles corresponds to a large portion of importance and are hence more meaningful to keep under careful management and control. Simultaneously, a large number of articles only have small importance and are thus less critical to control (Axsäter, 2006). By considering ABC classification as a three step model, a company first has to decide the number of classes to use, then choose appropriate *inventory policy measures* to define each class and finally choose *control parameters* to manage the articles allocated to each class, see figure 6.

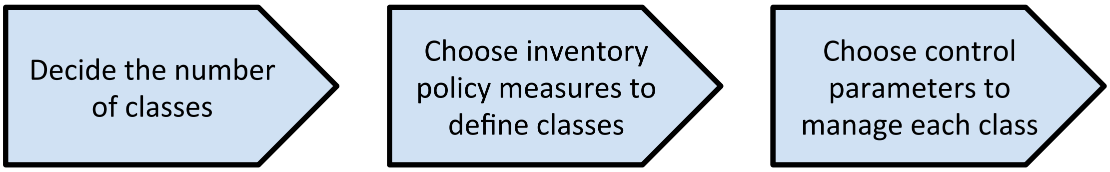

Figure 6. Considering ABC classification in three steps: to decide the number of classes, to choose inventory policy measures to define classes and to choose control parameters to manage each article class.

The original ABC classification structure considers three articles classes: class A, class B and class C, where the first class includes the high importance article tail, the last includes the low importance tail and the intermediate class considers the in between article segment, as described in figure 7. A common split is that class A includes the high-end 10 percent articles, class B the intermediate 30 percent and class C the low-end 60 percent (Axsäter, 2006). Another common allocation of articles is 10 percent, 20 percent and 70 percent in each class (Hadad & Keren, 2013). This relation between the number of articles and their relative importance is derived from Pareto's 80-20 rule, where about 20 percent of the articles account for 80 percent of the value (Chen, 2011). Even though the ABC classification originally was designed with three article classes, additional classes can be added if companies desire, however six classes are often considered to be the maximum (Teunter et al., 2009).

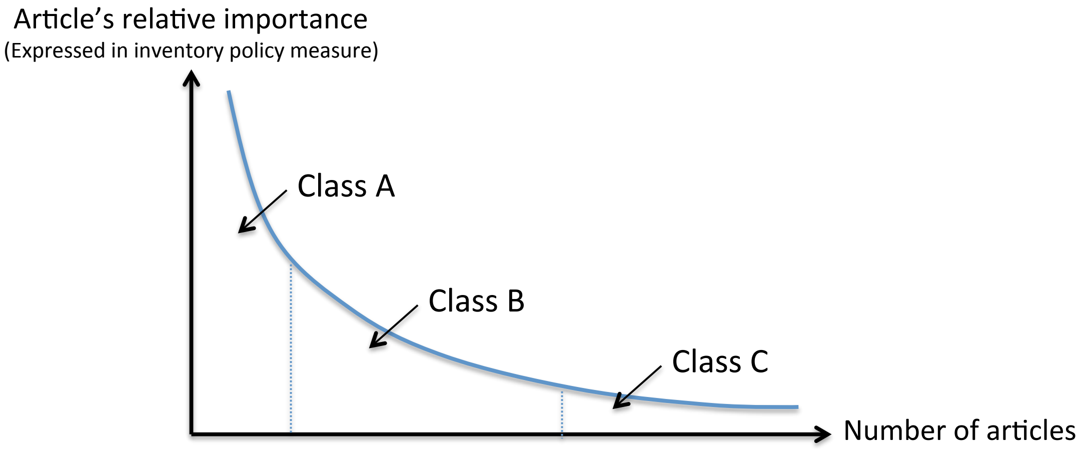

Figure 7. The basic idea of Pareto's 80/20-principle within ABC classification (Axsäter, 2006).

In addition to deciding the number of classes when working with ABC classification, *inventory policy measures* also have to be defined, which determine how important each article is. As Rudberg (2007) shows in table 2, different *inventory policy measures* are appropriate for different inventory performance goal areas. For example, if the inventory turnover rate is the primarily performance area of interest, each article's volume value, contribution to the margin and employed capital are well-fitted *inventory policy measures* (Rudberg, 2007).

Table 2. Proposed inventory policy measures with different goal areas (Rudberg, 2007).

Goal area	Inventory policy measures		
Inventory turnover rate	Volumue value	Contribution margin	Employed capital
Product characteristics	Criticality	Lifecycle phase	Error levels
Picking frequency	Transport time	Procurement time	Physical volume

Control parameters also have to be defined for each class, e.g. specific service level measures, size of *safety buffers*, amount of articles on hand or time on hand (Millstein et al., 2014). Two of the most frequently used *control parameters* are cycle service and fill rate, i.e. serv-1 and serv-2. Other possible ways to express *control parameters* are to separate between volume value service, demand service and order line service (Mattsson, 2011). One of the most challenging areas when working with inventory management is how to calibrate the *control parameters*, which is crucial for the inventory performance of any company (Teunter et al., 2009). An obvious question in this area is what *control parameter* level each class should get. For certain businesses, there is not even given which class that should have the highest or lowest *control parameter* level (Teunter et al., 2009).

Axsäter (2006) states a strong relationship between suitable *control parameters* and company characteristics. For example, if a manufacturing company uses volume value as *inventory policy measure* for an article inbound-inventory, it makes sense to keep low inventory of class A articles. The rational is that (1) all articles are interdependent so that production stops independently of what article that is missing and that (2) class A articles employ more capital than class B and class C articles and thus are more expensive to keep in inventory. At the same time, a finished goods-inventory should keep higher inventory of profitable and bestselling products (Gran, 2012).

Single criterion ABC classification

The traditional ABC classification approach is based on a single criterion: most commonly volume value, followed by demand volume (Teunter et al., 2009). The grouping into classes is done by looking at what relative weigh each article gets as a percent of the total volume value or other criteria used (Hadad & Keren, 2013).

The single criterion ABC classification approach has its primary advantage in simplicity, making the approach viable to implement for most companies at the same time as distinct guidelines are marked out. Anyhow, a single criterion approach also has several disadvantages as (1) no clear guidance to determine appropriate service levels for each class of articles, (2) since the grouping and service level decisions are made independently, there is an obvious risk for sub-optimisation, (3) the budget constraints are considered only at last in the process and thus there is a risk for infeasible solutions (Millstein et al., 2014). Working with single criterion ABC therefore often results in repeated revising before feasibility is reached.

Multiple criteria ABC classification

Deciding how to handle articles only by looking at one criterion at a time may sometimes be insufficient to provide satisfying inventory control. Multiple criteria approaches offer an alternative way to work with inventory control where several *inventory policy measures* are considered at the same time to reach satisfactory results (Hadad & Keren, 2013).

There exists different multiple criteria ABC classification approaches to optimise multiple *inventory policy measures* simultaneously. Some methods are able to consider a large number of *inventory policy measures*, but are computation heavy, e.g. principal component analysis (PCA) and artificial neutral network (ANN), while others are fairly easy to handle with moderate computations, e.g. double ABC classification (Chen, 2009 and Rudberg, 2007). Double ABC classification only considers two *inventory policy measures*, why it both is easier to understand as well as to use compared to the other multiple criteria ABC classification models.

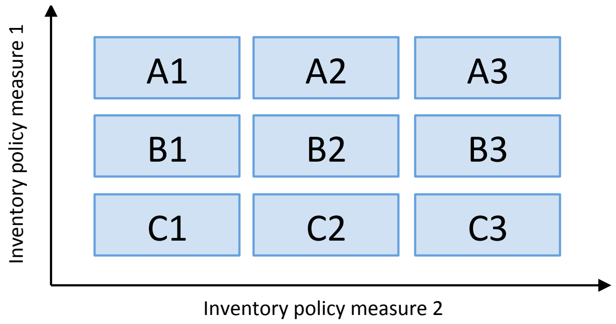

Figure 8. Graphical description of the idea behind a double ABC classification (Rudberg, 2007).

As visually emphasised in figure 8, going from a single to a double results in an increase of the number of article classes with a power of two (Rudberg, 2007). Teunter et al (2009) mentions scarcity of supply, rate of obsolesces, lead-time and cost of review as possible *inventory policy measures* to consider in multiple criteria ABC classification. Hadad and Keren (2013) further complement the list of *inventory policy measures* with the number of annual requests, commonality, substitutability, durability, reparability, order size requirement and demand distribution.

3.4 Lot sizing methods

There are two main reasons companies use lot sizing methods: financials and non-financials (Jonsson & Mattsson, 2009). Non-financial motives for lot sizing are found in organisations' environments and include minimum quantities in manufacturing processes and suppliers' minimum quantities to be able to place an order. However, the financial aspect is for most companies the dominant reason why considering lot sizing (Jonsson & Mattsson, 2009). When using lot sizing, there are two parameters to consider: the order quantity and ordering frequency, i.e. when to order and how much to order. There are methods using variable quantities and frequencies, methods using one variable parameter while keeping the other fix. Anyhow, keeping both order quantity and order frequency constant would risk driving infinite inventory levels or result in serious stock-out issues why this combination is not considered. Figure 9 below shows commonly used lot sizing methods and their characteristics.

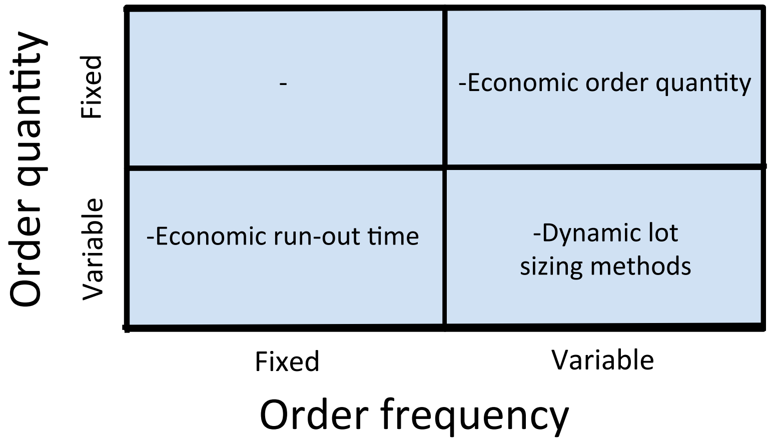

Figure 9. Different lot sizing methods and how they combine fix and variable parameters (Jonsson & Mattsson, 2009).

3.4.1 Semi dynamic models

A lot sizing method where either the order quantity or the order frequency is variable is referred to as semi dynamic model. Both combinations of variable and fix are described below, where focus is on the ability to find the economically best order quantity or order frequency.

Economic order quantity

The first lot sizing method to be discussed is the economic order quantity (EOQ), aiming to find an order quantity to be ordered each time to reach the lowest total cost (considering the *purchasing cost)*. Simultaneously, the time between two orders (the order frequency) changes based on the demand. The mathematical expression to calculate the EOQ is called the Wilson formula and is based on the cost of carrying inventory and the cost of ordering, expressed in equation 3.

$$C = \frac{Q}{2} \times P \times I + \frac{D}{Q} \times O \ (3)$$

Notations for equation 3-5:

C = *Total cost*
D = *Demand per time unit*
I = *Inventory-carrying factor*
O = *Ordering cost*
P = *Price per unit*
Q = *Order quantity*

The total cost is also expressed graphically in figure 10.

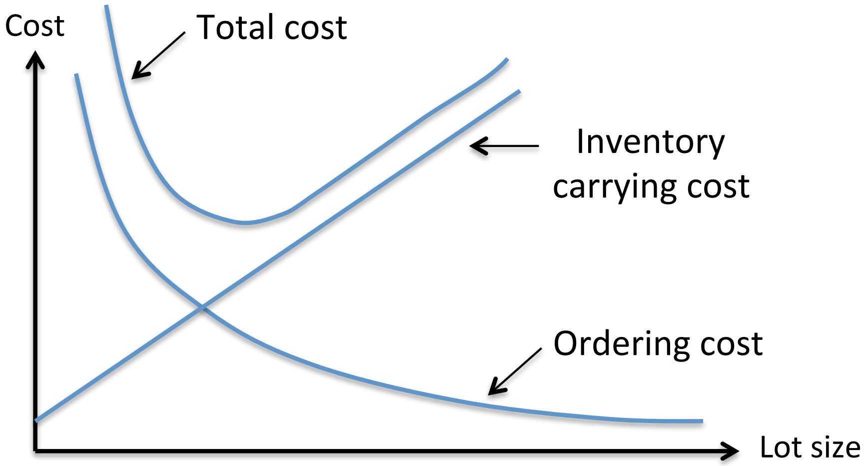

Figure 10. The inventory carrying cost and the ordering cost together add up to the total cost in the graph, corresponding to the total cost in equation 3 (Toomey, 2000).

Since this lot sizing method searches for the lowest total cost, differentiating the total cost with respect to order quantity gives the lowest total cost, expressed in equation 4. By solving the equation with respect to order quantity, the optimal order quantity is found, which is expressed in equation 5. However, it has to be mentioned that the EOQ formula does not consider any level of safety stock (Toomey, 2000).

$$\frac{dC}{dQ} = \frac{P \times I}{2} - \frac{D}{Q^2} \times O = 0 \ (4)$$

$$EOQ = \sqrt{\frac{2 \times D \times O}{P \times I}} \ (5)$$

The formula is rather simple to understand but is based on several assumptions: (1) the demand per time unit is known and constant, (2) ordering costs are fix and known over time, (3) the whole batch is delivered at once, (4) no shortage of articles is allowed, (5) and the *purchasing price* per article is known, constant and independent of the order quantity (Jonsson & Mattsson, 2005 and Axsäter, 2006). While the demand and the *purchasing price* usually is known from historical data or predicted by forecasting, the ordering costs and the inventory-carrying factor consist of several components and are required to be elaborated on more in detailed, which is presented later on in the chapter. If the demand is not constant and the demand for one period exceeds one EOQ the double amount needs to be ordered, which is why the demand is assumed to be constant.

Economic run-out time

The economic run-out time (ERT) is a lot sizing method with a fix order frequency and a variable order quantity, which is the opposite of the EOQ method. To calculate order frequency or ERT, the EOQ is first calculated and then divided by the average demand per period, expressed in equation 6. The result is an estimate of how often an EOQ is consumed and the average lot size ordered equals the EOQ. One of the strengths of ERT compared to EOQ is the automatic adoption to changes in demand. For example, if the ERT is calculated to two weeks, the order quantity increases with increasing demand during this period and decreases with decreasing demand (Jonsson & Mattsson, 2009). On the other hand, a variable order quantity can be challenging in terms of transportation utilisation, packaging and storing. When using ERT, the final ordering frequency is often rounded to an integer of time periods.

$$ERT = \frac{Economic\ order\ quantity}{Average\ demand\ per\ time\ unit} \ (6)$$

3.4.2 Dynamic models

Dynamic lot sizing methods use order quantities and order frequencies where both vary between consecutive orders. Thus, these methods require heavier calculations, but theoretically also offer more customised order placements (Jonsson & Mattsson, 2009). Dynamic lot sizing models compare the cost of keeping articles in inventory for future time periods with the costs of placing orders.

The Silver-Meal method is one of the most widely used dynamic lot sizing methods and is also known as the “least period cost” method. When determining how much to order in any period, demand in future time periods is considered and the only given is that at least period one’s demand has to be ordered (Axsäter, 2006). Using the Silver-Meal method, the average sum of inventory costs and ordering costs is considered to find the lowest total period cost. A calculation example is provided in table 3.

Table 3. The Silver-Meal method to determine order quantities and order frequencies

Input data	
Ordering costs per order (SEK)	200
Inventory cost (SEK/unit&week)	1
Stock on hand	0

Week	1	2	3
Demand	100	150	200

How much to order in week 1?		
If 1 week is included	200	SEK/week
If 2 weeks are included	(200+150*1)/2=175	SEK/week
If 3 weeks are included	(200+150*1+200*1*2)/3=250	SEK/week

The lowest average cost per week considering both ordering costs and inventory costs would be to order 100+150=250 units in week 1.

3.4.3 Components of lot sizing models

There are four central parameters that are used in most dynamic and semi-dynamic lot sizing methods described: the inventory-carrying factor, the ordering cost, the demand and the price. While the demand and the price are believed to be self-explained, the first two parameters are rather complex and are thus discussed below.

Inventory-carrying factor

As one of the most complex parameters, the inventory-carrying factor is a measure expressed in percent and used to determine how the total cost changes with the inventory level. There are three categories of costs to consider when talking about the inventory-carrying factor: capital costs, handling costs and risk costs (Piasecki, 2001). This relationship between these costs and the inventory-carrying factor is expressed in equation 7.

$$Inventory - carrying\ factor = Cost\ of\ capital + \frac{Handling\ costs + Risk\ costs}{Value\ of\ average\ inventory} \quad (7)$$

The cost of capital is usually regarded to be the dominant part of the equation and should have a similar magnitude as alternative investments (Axsäter, 2006). All capital that is needed to run businesses have a market price, which is the price a company has to pay to get access to the capital (Johansson & Runsten, 2005). The market price for capital can as a rate be divided into two parts: the risk-free rate and the rate associated with the risk of the investment, often referred to as the equity risk premium (Grabowski, 2013). The risk free-rate corresponds to the yield an investor would get from a risk-free investment, i.e. buying government bonds. Most common is to consider long-term bonds and Grabowski (2013) emphasises the 20-year U.S treasure yield as analysis standard in the United States. The magnitude of the equity risk premium is dependent on the perceived risk of not getting back lent capital and is dependent on macro- and micro-economical factors (Johansson & Runsten, 2005). Handling and risk costs are usually inferior to capital costs in magnitude and exactly which costs to include here depend on the company. The most commonly included factors are discussed later when calculating the inventory-carrying cost.

The cost of keeping inventory is not the same for each article and theoretically each article has its own inventory-carrying factor. To keep the amount of data manageable, companies usually set an average rate for all its articles (Jonsson & Mattsson, 2005). There are three main ways to determine the inventory-carrying factor: (1) by setting the factor as a company policy measure, (2) by calculating the factor based on actual observations in the *procurement process* or (3) by benchmarking used inventory-carrying factors from other similar organisations, (Mattsson, 2014a). The three approaches to set inventory-carrying factors are presented below.

By letting the inventory-carrying factor be a policy measure, it can be used to reach other targeted company goals, often to reduce employed capital in inventories. This means that the factor is used as a dynamic tool to reach overall goals rather than as an input based on the real data (Mattsson, 2014a). Hence, a policy-based inventory-carrying factor does not even have to be close to the reality and this explains why presented observations of used factor go as high as up to 50 percent (Mattsson, 2014a).

When calculating the inventory-carrying factor, Jonsson and Mattsson (2009) present twelve cost types to consider[1]. Not all of these twelve are relevant for every product and therefore no relative order of importance is presented. Anyhow, to get an indication of relative importance, an IOMA/Harding survey pinpoints the most frequently considered cost types. In decreasing order the most frequently considered costs were cost of money (100 percent), obsolescence (58 percent), inventory space (50 percent), taxes (42 percent) and insurance (42 percent). Two thirds of the respondents in the survey where manufacturing companies (Anonymous, 2005). An important reason why cost of money is more frequently considered than handling and risk costs is because the inventory carrying factor concerns the cost of keeping more or less inventory, not whether or not to have inventory (Jonsson & Mattsson, 2005). Nevertheless, for some businesses where articles are largely sized, the temperature has to be controlled or where inventory space has to be rented, the handling costs play a more central role (Jonsson & Mattsson, 2005).

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[1] Presented in Appendix 2

The benchmark-based inventory-carrying factor approach uses information about what inventory-carrying factor other similar organisations are using. This information should be taken from organisations with similar production processes, for example from competitors or from other divisions within the own company. Literature and handbooks are also commons way to find inventory-carrying factors to benchmark (Jonsson & Mattsson, 2005). Anyhow, if benchmarking the inventory-carrying factor, one might not know if it is a factor based on policy, calculation or prior benchmarking.

The different approaches to set the inventory-carrying factor, together with different business environments, results in that companies are using widely different inventory-carrying factor levels. Olhager (2000) has observed that the used factors span between 15-40 percent and Mattsson (2014a) has through his observations presented a range from 10 to 50 percent. Mattsson (2014a) further estimates the most frequently used factor-level to the interval between 20 and 25 percent.

Ordering costs

Ordering costs are defined as all incremental costs that are generated when performing the ordering process. Incremental costs in this context refer to all costs directly dependent on the number of placed orders, without consideration to the ordered quantity (Jonsson & Mattsson, 2009). Ordering costs have to be set to perform calculations of economic order quantities and ERT, as well as for dynamic lot sizing methods as the Silver-Meal method. As with the inventory-carrying factor, each item has a specific ordering cost in reality, but due to simplicity reasons the calculations are usually set to get an average ordering cost.

Ordering costs can, as with the inventory-carrying factor, be found by policy, calculation and benchmarking. There are two major ways to calculate the ordering costs for an organisation, by going top-down or by going bottom-up. A top-down approach means that the total amount of variable ordering costs, i.e. the total time spent on material planning, purchasing, order handling etc., is divided on the total amount of order lines, see equation 8.

$$Top - down = \frac{Total\ amount\ of\ variable\ ordering\ costs}{Number\ of\ order\ lines} \quad (8)$$

$$Bottom - up = Hourly\ rate \times Time\ \ per\ order\ line\ for \begin{cases} Place\ order + \\ Send\ invoice + \\ Goods\ reception + \\ Inspection + \cdots \\ (full\ list\ in\ Appendix\ 3) \end{cases} \quad (9)$$

When a bottom-up method is used (see equation 9), the calculation should be done over a longer time period, e.g. one year, to protect against external and internal short-term fluctuations. Also when using a top-down calculation, one has to be aware of short-term fluctuations, but since the overall capacity considered, fluctuations get smoother due to the central limit theorem[2]. Jonsson and Mattsson (2009) have complied a list of 15 potential costs when calculating the incremental ordering costs, where costs for personnel, data processing, transportation and handling generally are the most heavily weighted ones. The whole list of cost types is found in appendix 3. Not all of these cost types exist for every purchase article and when procuring call-off based articles, costs for quotation requests, negotiation with and selection of suppliers should not be included (Jonsson & Mattsson, 2009).

3.4.4 The importance of optimal order quantities

Since theory describes a situation where each article should have its own inventory-carrying factor and ordering cost, but where averages usually are used in reality, it is relevant to ask how important it is to use the optimal order quantity or frequency.

By using equation 3, equation 4 and equation 5 from chapter 3.4.1, equation 10 is obtained (Axsäter, 2006).

$$\frac{C}{C^*} = \frac{Q}{2}\sqrt{\frac{P \times I}{2 \times O \times D}} + \frac{1}{2 \times Q}\sqrt{\frac{2 \times O \times D}{P \times I}} = \frac{1}{2}\left(\frac{Q}{EOQ} + \frac{EOQ}{Q}\right) \quad (10)$$

Notations for equation 10:

C = *Total cost*

C^* = *Optimal total cost*

D = *Demand per time unit*

I = *Inventory-carrying factor*

O = *Ordering cost*

P = *Price per unit*

Q = *Order quantity*

The equation states that the cost increase due to not using the EOQ is solely dependent on the relation between Q and EOQ. Axsäter (2006) argues that even a considerable difference between Q and EOQ results in minor cost increases. As an example, Axsäter (2006) highlights that an order quantity 50 percent higher than the economically optimal only results in an 8 percent cost increase. Another interesting feature of equation 10 is that changes in ordering costs result in even smaller cost increases, where a 50 percent too high ordering cost only results in a 2 percent increase of total costs (Axsäter, 2006). Mattsson (2014c) prove the same relation and conclude that the EOQ have a certain roughness that allows the user to round to the closest integer or even to a full pallet without having any severe effect on the total cost. Order quantities 50 percent larger than the EOQ increases the total cost with 8,3

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[2] Central limit theorem is a statistical formula stating that the sum of many small samples will become normal distributed.

percent and order quantities 50 percent smaller than the EOQ result in a 25 percent cost increase, see figure 11 (Mattsson, 2014c).

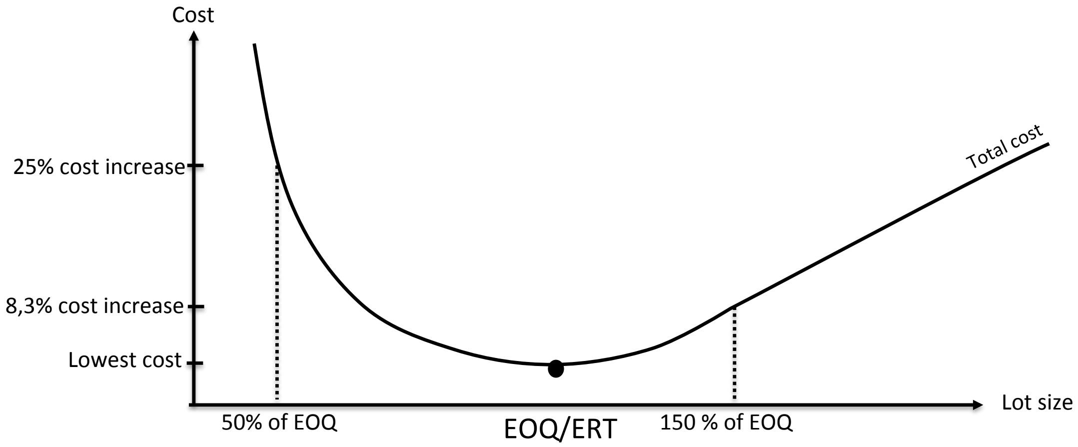


Figure 11. The economic effect on procurement costs when the order quantity differs from the economically most beneficial level (Mattsson, 2014c).

3.5 Service levels

Keeping control of the inventory's capability to supply the production with necessary components is an important management tool for manufacturing companies. The level of customer satisfaction (for both internal and external customers) depends on the manufacturing company's capability to respond to orders with promptness. Many organisations are facing a challenging trade-off between keeping low inventory levels and to keep a high customer satisfaction level through on-time deliveries, seen in figure 3, chapter 3.1.

There are two major service level types, widely used to keep control and manage companies' inventories and thereby the successes of responding to customer demands (Shivsharan, 2012). These two measures are referred to as cycle service (serv-1) and fill rate (serv-2). The cycle service measure expresses the probability of not stocking out over a planning period (an inventory cycle), whereas fill rate denotes the proportion of demand that can be satisfied with current inventory. Mattsson (2013) confirms cycle service and fill rate's dominating position by showing that almost all Swedish companies using theoretical service levels follow either cycle service or fill rate. As the definitions suggest, the cycle service and the fill rate express two totally different things, seen in equation 11 and equation 12 (Jonsson & Mattsson, 2009).

$$Cycle\ service = 1 - \frac{No.of\ inventory\ cycles\ with\ shortage}{Total\ no.\ of\ inventory\ cycles} \quad (11)$$

$$Fill\ rate = \frac{Part\ of\ demand\ that\ can\ be\ delivered\ directly\ form\ stock}{Total\ demand} \quad (12)$$

To further emphasise the difference between the two major service level measures, an example is presented below in table 4. The example data covers ten order cycles where the total demand is 1’000 articles, backorders occur during three of the order cycles with a total of 100 articles. When measuring cycle service, the fictive company would have performed a 70 percent service level, while if measuring fill rate, the same company would have performed a 90 percent service level.

Table 4. An example where 7 out of 10 order cycles are completed without stock-outs, i.e. 70 % cycle service level is reached. This while 900 out of 1’000 articles are delivered on time, i.e. 90% fill rate.

Order cycle	Demand in the cycle	Number of articles that stocked out
1	100	0
2	150	25
3	100	0
4	100	0
5	50	0
6	50	25
7	150	0
8	100	50
9	100	0
10	100	0

To summarise, the two main ways to measure service level offer various features with both advantages and disadvantages. The fill rate may be easier to grasp, while cycle service as a concept sometimes is challenging to fully understand. On the other hand, the cycle service measure is simpler to calculate. The fill rate has the property of systematically give lower average service level than what it is dimensioned to be (Mattsson, 2013). One reason is due to the fact that the fill rate-measure assumes each transaction to equal a single article even though this is rarely the case (Mattsson, 2013). Another reason is that when companies applies the theoretical models in reality it is common to assume that the distribution of consumption is normally distributed, which rarely happens in practice. Still, Mattsson (2013) has through simulations shown that distribution errors only has minor impact while the difference in transaction size has significant effect on the average service level. It is possible to further divide fill rate into different definitions. Both Taras and Taras (2014) and Mattsson (2014a) mention order line fill rate and value fill rate as frequently used definitions, both presented briefly below.

Order line fill rate

Order line fill rate is a widely used modification of the fill rate-measure. Customer orders or production orders normally include more than one article. The order line fill rate-measure describes the fraction of order lines that are fully delivered in relation to the total number of order lines (Taras & Taras, 2014). For example, consider a company order that includes 10 different article numbers, but only 7 article numbers are fully delivered on time. Since not all article numbers are delivered on time, the order line fill rate adds up to 70 percent, which does not have to correspond the fraction of articles delivered on time (Exerve, 2014). Mattsson (2011) presents that the order line fill rate always is less or equal to the fill rate. Through simulations Mattsson estimates the order line fill rate to be between one and three percent lower than the fill rate. Only if the order line fill rate has orders of one the order line fill rate and fill rate would be equal Mattsson (2011).

Value fill rate

The value fill rate-measure is also a modification of the fill rate-measure, but considers the fraction of value and not quantity delivered on time. By taking both volume and price of each article into account, the value fill rate-measure weights each article individually (Taras & Taras, 2014).

3.6 Safety buffers

Safety buffers are used to protect inventories from running out of stock. Safety stock and safety time are two basic ways to create *safety buffers* (Jonsson & Mattsson, 2009). A safety stock uses a quantity of articles to mitigate the risk of inventory deficit, while a safety time uses time to mitigate the inventory deficit risk by rescheduling orders to be delivered prior to the actual demand (Alves et al., 2004). Whether it is preferable to use time or quantity depends on company characteristics and environment.

3.6.1 Safety time and safety quantity

When demand uncertainty is involved, a safety stock usually outperforms the use of safety time, while safety time is advantageous when lead-time uncertainty is strong (Mattsson, 2014d). Nevertheless, it has been concluded by Buzacott and Shanthikumar (1994) that safety time is preferable to safety stock when high quality forecasting exists, whilst Alves et al. (2004) argues that safety time loses its relative attractiveness to safety stock when considerable demand uncertainty occurs during lead-time. It can be concluded that safety time only is preferable if future orders can be forecasted in a accurate way, otherwise safety stock is more robust towards changes in customer requirements (Buzacott and Shanthikumar, 1994).

It is further important to understand how safety times and safety stocks are interdependent. When an article is delivered prior to actual demand, the result is that the company holds a safety stock from the delivery date until when the actual demand occurs. Since the successive deliveries also would be delivered prior to actual demand, a zero inventory level is never reached and a safety stock is generated, see figure 12.

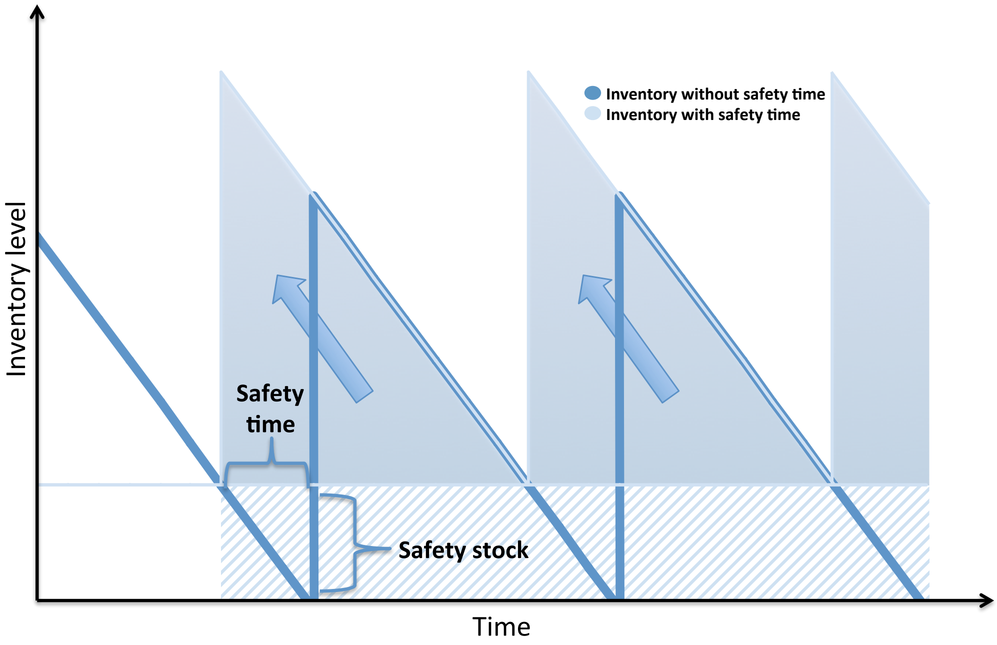


Figure 12. The graph shows how a permanent safety time is transformed into a corresponding safety stock (Kampen et al., 2010).

As seen in the figure, order frequency, order quantity and demand rate are all fix, which seldom happens in practice. Instead of a reality check, the simplified case is more an explaining example of the relationship between safety time and safety stock, see equation 13 (Kampen et al., 2010).

$$Safety\ stock = Safety\ time \times \frac{Annual\ consumption}{Number\ of\ days\ with\ production\ per\ year} \quad (13)$$

If using the same *safety buffer* for all articles, the ones with low variations in demand will have an unnecessary high *safety buffer* while articles with high variation in demand will have too low *safety buffer* to satisfy the customer. In general one *safety buffer* for all articles leads to unnecessarily capital employed compared to the average service level achieved (Mattson, 2014d). To be able to generate appropriate *safety buffers* for each article, it should be derived from a set service level, why *safety buffer* calculations are discussed below.

3.6.2 Calculating safety buffers

Company can choose to either manually estimate an appropriate *safety buffer* level based on experience and soft estimates or to use more sophisticated calculations to calculate a theoretically optimal buffer, which this chapter focuses on. In the service level chapter, fundamental differences between cycle service and fill rate were emphasised. Anyhow, both measures are built on similar assumptions, which are displayed when looking into how to calculate both cycle service and fill rate. Both models require information about both supply and demand uncertainties during the lead-time (Alves et al., 2004). The variations, both for supply and demand, are usually considered to be normally distributed when calculating *safety buffers*. Supply uncertainty is in theory often referred to as lead-time uncertainty. A common way to estimate the standard deviation during the lead-time is to first estimate the standard deviation per time unit according to equation 14, where the mean absolute deviation (MAD) is used (Toomey, 2000).

$$\sigma_D = 1{,}25 \times MAD_D \ and \ \sigma_{LT} = 1{,}25 \times MAD_{LT} \ (14)$$

Notations for equation 14-19:

D	= *Average demand per time unit*
$E(z)$	= *Service loss function*
k	= *Safety factor*
LT	= *Average lead-time in time units from order to delivery*
MAD_D	= *Mean average deviation of demand*
MAD_{LT}	= *Mean average deviation of lead-time*
Q	= *Average order quantity*
SS	= *Safety stock*
z	= *Service loss function safety factor*
σ_D	= *Standard deviation of demand during the time period*
σ_{DDLT}	= *Standard deviation of demand during lead-time*
σ_{LT}	= *Standard deviation of lead-time*

Mattsson (2013) pinpoints the importance of calculating the mean absolute deviation based on historical data. He also emphasises the importance of using a large sample of historical data when calculating the standard deviation. In a study, Mattsson (2013) shows that a size of 40 samples gives a correctness of ±10 percent. The standard deviation per time unit is used to calculate the standard deviation during lead-time, expressed in equation 15 (Jonsson & Mattsson, 2009).

$$\sigma_{DDLT} = \sqrt{LT \times \sigma_D^2 + \sigma_{LT}^2 \times D^2} \ (15)$$

Since demand variations tend to be of greater magnitude than lead-time variations, it is common to assume lead-times to be constant (Jonsson & Mattsson, 2009). Under these circumstances, the total standard deviation is calculated in equation 16.

$$\sigma_{DDLT} = \sigma_D \times \sqrt{LT} \ (16)$$

The calculations of standard deviations are based on raw data from a business and do not consider any specific service level measure. Thus, both cycle service and fill rate are until here mathematically handled the same way. When turning the standard deviation into an actual service level, the calculations start to differ (Jonsson & Mattsson, 2009). The cycle service measure has a simpler structure and its calculation procedure is expressed in equation 17, where the safety stock is calculated from a safety factor and previously calculated standard deviation. Chosen cycle service level is used as an input to find the safety factor in a normal distribution table, see appendix 4.

$$SS = k \times \sigma_{DDLT} \ (17)$$

Fill rate calculations include more steps than for cycle service and are thus considered more complex. Instead of directly calculating a safety stock, the service loss function value E(z) is calculated, as in equation 18. The service loss function value is then used to get a z-value from a service loss function table, see appendix 5. The z-value is combined with the predefined standard deviation, see equation 19.

$$E(z) = \frac{(1 - Fill\ rate\ level)}{\sigma_{DDLT}} \times Q \ (18)$$

$$SS = \sigma_{DDLT} \times z \ (19)$$

3.7 Complementary factors

To support interesting empirical findings in an inventory turnover rate perspective, the theoretical framework has been extended. The human aspect and material planning methods are thus discussed in this chapter.

3.7.1 The human impact

There are many obstacles when theoretical models are applied in real businesses and one of them is the human factor. Every decision maker must adjust the theoretical models to the real situations and therefore take decisions regarding sizes of order quantities or when to get deliverers (Mattsson, 2014b). Mattsson (2014b) emphasis that the most common behaviour is to order more and earlier than the theoretical models suggest, which leads almost invariably to unnecessary high inventory levels and to longer lead-times. The decision to increase order quantities could be due to habits of the employees where shortage in inventory is seen as a worse scenario than high levels of inventory. This since a shortage effects the production directly and therefore the service level to customers. Employees are likely to take decisions involving personal gains and not to only look at the company's performance (Rubenowitz, 2004). Since the measure of service level to production or customer increases if shortages are avoided, high inventory levels most often help the employees to keep out of trouble. Other reasons than habits for ordering larger quantities could be due to quantity discounts or due to employees urge to decrease the number of ordering occasions. Mattsson (2014b) describes how an order quantity can grow throughout a company's different divisions where everyone has its own incentives and opinions. The same could be seen with order delivery occasions, where different parts of an organisation move the delivery earlier due to habits or own interest. Another issue is that lead-times are most often rounded up to the closest integer of entire weeks, which create longer lead-times (Mattsson, 2014b).

3.7.2 Material planning methods

There are several methods for planning new orders that all determine when orders are sent to suppliers and when inbound deliveries take place (Jonsson & Mattsson, 2009). The four most common methods are the re-order point system, periodic ordering system, run-out time planning and material requirements planning. The following chapters briefly describe these methods.

Re-order point system

A re-order point system is a material planning method that uses a reference quantity, which is compared to the available stock on hand (Jonsson & Mattsson, 2009). If the stock on hand is lower than the reference point, a new order is placed. The reference point, also called the re-order point, is calculated as in equation 20. When using a re-order point system, the order quantity is fix while the intervals between orders vary from time to time.

$$ROP = SS + D \times L \ (20)$$

Notations for equation 20-22:

D = Demand per time unit
L = Lead-time
Q = Order quantity
R = Re-ordering interval
ROP = Re-order point
S = Stock on hand
SS = Safety stock
T = Target level

Periodic ordering system

A periodic order system is a material planning method that instead of calculating when an order needs to be placed, calculates how much to order every time an order should be placed (Jonsson & Mattsson, 2009). To do this a fix interval between order placements need to be specified and a target level needs to be calculated. The calculations for the order quantity and target level are shown in equations 21 and equation 22.

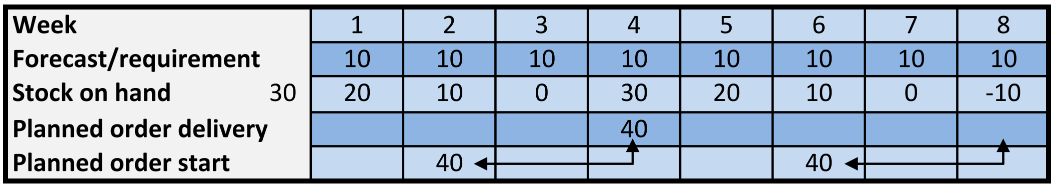
$$Q = T - S \ (21)$$

$$T = SS + D \times (R + L) \ (22)$$

Run-out time planning

The run-out time planning is closely related to the re-order point system, but the remaining stock on hand is calculated in time instead of in quantity (Jonsson & Mattsson, 2009). The run-out time is calculated by dividing the stock on hand with the average daily consumption. A new order is placed if the run-out time is less than the safety lead-time plus replenishment lead-time.

Material requirements planning
The material requirements planning (MRP) is a system that schedules new inbound deliveries by calculating when the stock on hand will become negative (Jonsson & Mattsson, 2009). The system can be illustrated by looking at the example provided in figure 13. Here the MRP has a horizon of eight weeks with forecasted or real requirements of ten each planning period. The stock on hand starts at a level of 30 and is thereafter calculated down each week after the requirements for the same week. The lead-time for inbound delivery is in this example two weeks and is illustrated in week two when an order should be placed and that same order will arrive in week four. In week eight the stock on hand would be negative if no orders arrive that same week, the system then tells that an order needs to be placed in week six to avoid deficit in inventory.



Week		1	2	3	4	5	6	7	8
Forecast/requirement		10	10	10	10	10	10	10	10
Stock on hand	30	20	10	0	30	20	10	0	-10
Planned order delivery					40				
Planned order start			40				40		

Figure 13. Example of how an MRP-system planning orders (Jonsson & Mattsson, 2009).

The MRP-system could advantageously be used for many products and all its articles, by breaking the products down with a bill-of-material. The MRP can make us of different planning periods to make use of more detailed plans in short-term when requirements are well known. Still the planning horizon must at minimum be equivalent to the longest time for purchasing and production for any given article (Jonsson & Mattsson, 2009).

4 EMPIRICAL FINDINGS

The data and information used for the following part has been collected through empirical studies at UCMSWE's production site in Mölnlycke, Sweden. Most of the quantitative data has been collected directly from UCMSWE's *MPC-system*, which the company for long has been using in its day-to-day operations. The first part covers relevant company specifics, which have been described to get a holistic view of UCMSWE. The second part deals with the current procurement model at UCMSWE and its influence on the inventory levels. The last part discusses other factors influencing the inventory levels.

4.1 UCMSWE - company description

At the production site in Mölnlycke, UCMSWE manufactures forklifts with two different brands: Atlet and Nissan. UniCarriers (UCMSWE's mother company) has in total about 1'000 employees of which approximately 240 work at the production site in Mölnlycke. UCMSWE has a turnover of about 1,8 billion SEK and has a capacity of producing 12'000 units per year. However, the current production rate is approximately 6'500 units per year.

UCMSWE offers 38 different model series of forklifts that are both for indoor and outdoor use. The production lines are flexible to meet the customer demand of highly customer specific forklifts. UCMSWE also provides a total solution service where logistic solutions, training and other services are offered.

4.1.1 Organisation

UCMSWE's purchasing and logistics function has been the focal division for this research and can be divided into three areas: strategic purchasing, material planning and logistics, see figure 14. The strategic purchasing division includes seven employees who are responsible for establishing supplier agreements. The material planning division has four employees who are responsible for daily call-off procurement through the *MPC-system*. Their responsibility is to keep reasonable inventory levels by sending order requests based on suggestions from the *MPC-system*. The logistics division consists of two employees who are in charge of inbound, outbound, internal and external transportation.

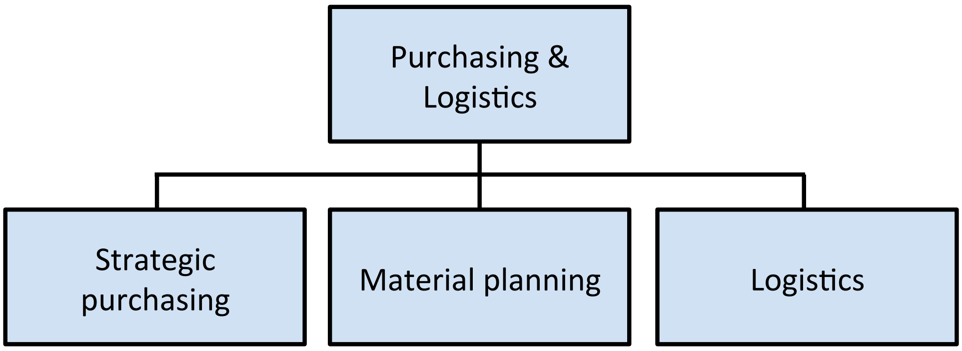


Figure 14. The organisation structure of UCMSWE's purchasing and logistics division.

4.1.2 Products

UCMSWE's product portfolio with 38 forklift models includes both counterbalance and warehouse forklifts and are powered with combustion engines or batteries. Generally, the heavy-duty forklifts are built with counterbalance technology and use combustion engines as power source while the warehouse forklifts are battery powered. The company's forklifts have carrying capacities to satisfy all customers' needs up to 5'000 kg, delivered by the heavy-duty Atlet Balace GH/DH model, see figure 15.

Figure 15. To the left, Atlet Balance GH/DH which is the company's top model in terms of carrying capacity, lifting up to 5'000 kg. To the right, Atlet Ergo ATF which is one of the company's smaller battery powered warehouse forklifts.

4.1.3 MPC-system

The *MPC-system* at UCMSWE is an information system called Multi and has been used for many years in the organisation. The material planning method used in Multi is an MRP-system that calculates when supplier orders need to be placed according to inventory levels, customer orders and forecasted demand in the system. UCMSWE's material planners follow the inventory levels for each article, which in general is given as a time measure. The system automatically suggests when new orders should be placed and the system is programmed to move orders three days earlier, which generates a *safety buffer* of three days for all articles.

4.1.4 Forecast based articles

The purchasing and logistics division is responsible for procurement of all UCMSWE's articles but the scope of this thesis has not been to cover all these. Focus has been on articles that are managed with UCMSWE's ABC-matrix, i.e. the *forecast based articles*. Other articles, for example customer or order specific articles, are more volatile in their demand and have to be handled in a less standardised manner.

The *forecast based articles* correspond to the vast majority of UCMSWE's volume value within purchasing and cover about 3'400 unique articles. After gathering data from 2013's production and purchasing activities, some articles were removed due to incomplete information, e.g. no consumption during 2013 or articles that recently were phased in or out. 2'666 unique articles remained with complete data, having a total volume value corresponding to 93 percent of all *forecast based articles'* volume value. Because of this limited 7 percent point drop in volume value, the research was still considered to be able to give a good recommendation of how to improve the inventory turnover rate at UCMSWE. The effect on both the number of articles and the volume value from the exclusion of articles with non-complete information is presented in table 5.

Table 5. The number of articles and amount of volume value that is lost due to incomplete information about the forecast based articles.

	All forecast based articles	➔	Articles with complete information
Number of unique articles:	100%	➔	79%
Volume value of unique articles:	100%	➔	93%

When looking at the remaining *forecast based articles*, the volume value spans considerably. The top article during 2013 had a volume value of over 8 million SEK while 90 percent of the articles counted for volume values below 200'000 SEK each. The articles' volume values have the characteristics of a Pareto distribution, where a few articles represent the majority of the value.

4.2 Current procurement model

After the brief introduction of UCMSWE, this chapter funnels down the scope to describe the focal area of the company: the current procurement model. The empirical findings cover lead-times, ABC classification, lot sizing, *safety buffers* and delivery windows. The inventory turnover rate is also described together with the connection between these areas.

4.2.1 Lead-times

The definition of lead-time differs depending on the context and it has therefore been important to clearly state the time measures used at UCMSWE. The lead-time measure in this thesis relates to the lead-time during the *procurement process* at UCMSWE. The order process has been divided into three time intervals and four occasions, see figure 16.

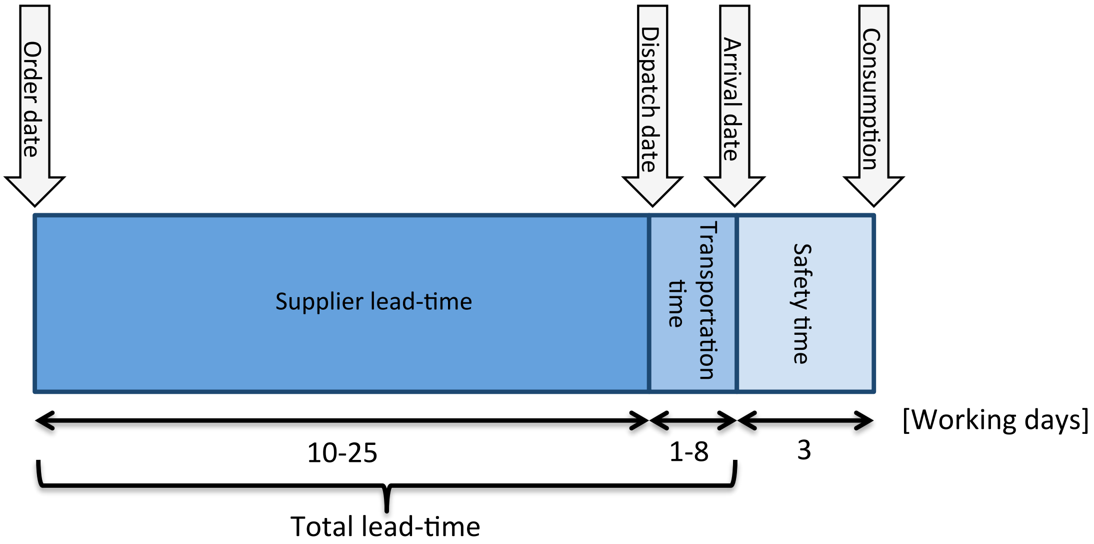


Figure 16. Time intervals and occasions related to the lead-time during the procurement process at UCMSWE.

The four occasions are the order date, the dispatch date, the arrival date and the consumption date. The order date is when the order is placed and sent to the supplier. At the same time the supplier lead-time begins. This time is defined in the purchasing agreement and is fix until the parties agree on changes. The supplier lead-time ends when the order is picked up from the supplier, the dispatch date. The supplier lead-time varies from supplier to supplier but 96 percent are within the span of 10 to 25 working days. Each supplier has one or two fix dispatch days per week, set by UCMSWE to control the inflow and avoid heavily fluctuating volumes of inbound deliveries from day-to-day.

After the order has been shipped, at the dispatch date, the transportation time starts. The company's suppliers of *forecast based articles* are primarily located in Europe, which makes it possible to keep relatively short transportation times. All considered suppliers have an estimated transportation time between 1 and 8 working days, depending on location and available transportation solutions. All inbound transportation of *forecast based articles* is carried out with road transport, where UCMSWE owns the ordered articles during the transportation time. Third party logistic solutions including both milk rounds and direct deliveries are used for most inbound transportation, which the company pays for. Due to the cost of transportation, a standard price factor is added to each article's *purchasing price* to account for the increased costs when calculating value of inventory. The transportation time ends when the shipment arrives at UCMSWE.

The arrival date is planned to occur three working days before the consumption date, which is when the first article from an order is needed in production. The supplier lead-time together with the transportation time is hereafter referred to as the *total lead-time*.

4.2.2 The ABC-matrix

UCMSWE is currently using an ABC-matrix to decide each *forecast based article's* order frequency through classification into three main classes: A, B and C. Each main class holds articles within a specific volume value span, where the volume value is defined as the article's *purchasing price* times its annual consumption. Class A contains the articles with the highest volume values (above 145'000 SEK annually), class C holds the low volume value articles (below 25'000 SEK annually) and class B includes all intermediate articles. Each main class is segmented into two or three subgroups: A1-A3, B1-B3 and C1-C2. These subgroups consider a second *inventory policy measure*: the annual consumption, where the articles with the highest consumption are allocated to the first subgroup (e.g. A1) and the articles with the lowest consumption in the last subgroup (e.g. A3), see table 6. Counting all subgroups, UCMSWE's ABC-matrix has eight classes to distribute its articles into. The main article class boundaries were set to match a Pareto distribution where 10, 20 and 70 percent of the articles are placed into class A, B and C.

Table 6. The ABC-matrix that currently is used by UCMSWE to classify its forecast based articles.

Category	Volume value (T SEK)	Annual consumption	Safety stock (% of annual consumption)	Order frequency (Times/year)
A1	> 145	> 1000	0	48
A2	> 145	500 – 1000	0	36
A3	> 145	< 500	0	24
B1	25 – 145	> 1000	0	24
B2	25 – 145	150 – 1000	0	12
B3	25 – 145	< 150	0	4
C1	4 – 25	–	8	4
C2	< 4	–	8	1

Each class is as described above defined by two *inventory policy measures*: volume value and annual consumption. Each class also have two *control parameters*: safety stock and order frequency. The order frequency is chosen so that deliveries could be done at most once a week, down to once a year. The highest order frequency is given to the class with the highest volume value and consumption and is thereafter decreasing for each succeeding class. For class C1 and C2 there is also a safety stock corresponding to 8 percent of the annual demand for each article. The other classes do not have any safety stock according to UCMSWE's ABC-matrix. The use of its ABC-matrix is graphically described in figure 17.

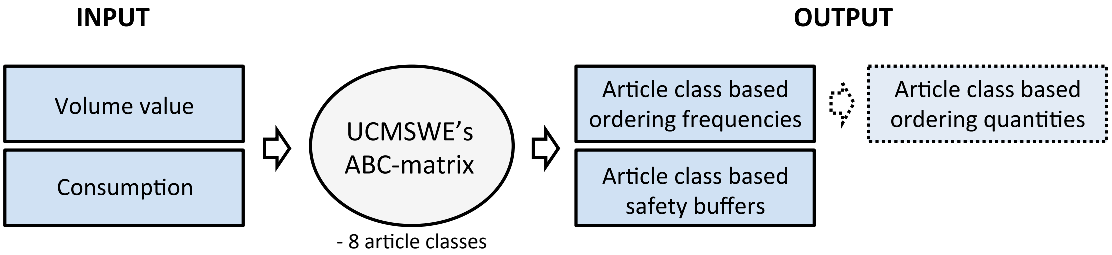


Figure 17. A graphical description of the ABC-matrix used at UCMSWE today.

UCMSWE states that its motives behind using an ABC classification is to decrease the *procurement cost* by getting more frequent deliveries of expensive articles and thereby smaller order quantities, without ordering too small batches of articles with low annual consumption. The ABC-matrix is a useful tool for the purchasers to give an idea of reasonable order sizes when negotiating contracts with UCMSWE's suppliers.

Even though UCMSWE perceives its ABC-matrix to be useful, they feel there are many uncertainties associated with today's structure. This has made UCMSWE to think that the order quantities generated today may not be optimal to support the purchasing function and thus could result in suboptimal inventory levels. Additionally, input and output parameters do not have any distinct way to being updated or changed, which strengthens the probability of running a sub-optimised model.

4.2.3 Order quantities

The following chapter describes how order quantities of *forecast based articles* are determined at UCMSWE. The process to determine order quantities includes activities from forecasting of future demand to actual orders. To get a holistic picture of how UCMSWE works with order quantities, the process has been structured into three steps. Further, to avoid confusion about the meaning of order quantities in different contexts, the following three definitions are stated and used throughout this thesis: the *theoretical order quantity* refers to the order quantity calculated by the ABC-matrix directly from forecasted demand without consideration about constraints and the *MPC-system order quantity* refers to the order quantity used as input in the *MPC-system*. The *actual order quantity* refers to the order quantity ordered from suppliers. The sequence of going from *inventory policy measures* to an *actual order quantity* is showed in figure 18.

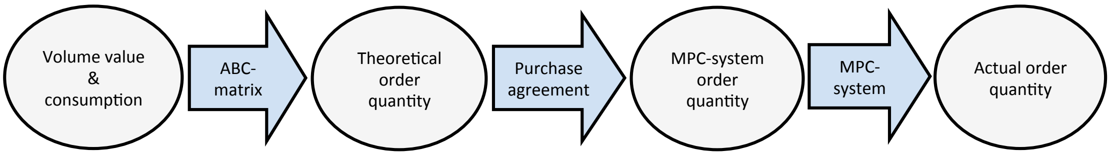


Figure 18. The sequence of going from inventory policy measures to actual order quantity.

Determining the theoretical order quantity

The first step in the process of determining how much to order is to go from a forecasted demand to a *theoretical order quantity*. UCMSWE forecasts the annual consumption, which also gives the volume value. Depending on the values of these two parameters, each article is allocated into an article class in the predefined ABC-matrix, see table 6 in chapter 4.2.2. A *theoretical order quantity* is then calculated by taking the forecasted annual consumption divided by the order frequency given to the article's ABC-matrix class, see equation 23.

$$Theoretical\ order\ quantity = \frac{Forecasted\ annual\ consumption}{Order\ frequency\ from\ the\ ABC - matrix} \quad (23)$$

Today, UCMSWE's *theoretical order quantities* span from 1 to 5'000 articles per order, where the absolute majority have a quantity between 1 and 200 items. The distribution of articles by *theoretical order quantity* is expressed in figure 19.

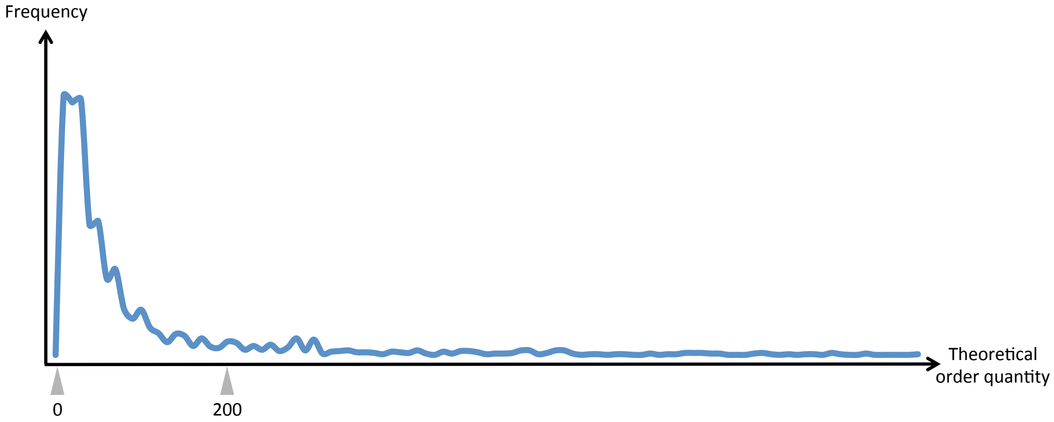


Figure 19. The distribution of theoretical order quantities for UCMSWE's forecast based articles.

UCMSWE is using the *theoretical order quantity* to get an indication of how much to order each time to maintain reasonable inventory levels. By using the ABC-matrix, UCMSWE has been able to get guidance without getting overburden with data.

Determining the MPC-system order quantity

The second step in the process to determine order quantities is when *theoretical order quantities* are used as a foundation by UCMSWE's strategic purchasing department to establish supplier agreements. The supplier agreements include order quantities for all *forecast based articles* and these order quantities are then entered as input in UCMSWE's *MPC-system*. These entered order quantities are referred to as *MPC-system order quantities*, which not always correspond to the theoretically calculated quantities. The empirical findings show that the *MPC-system order quantities* span between 1 and 6'000. In fact, the empirical study shows that only one in three *forecast based articles* had an *MPC-system order quantity* within a ± 20% interval from the *theoretical order quantity*, see figure 20.

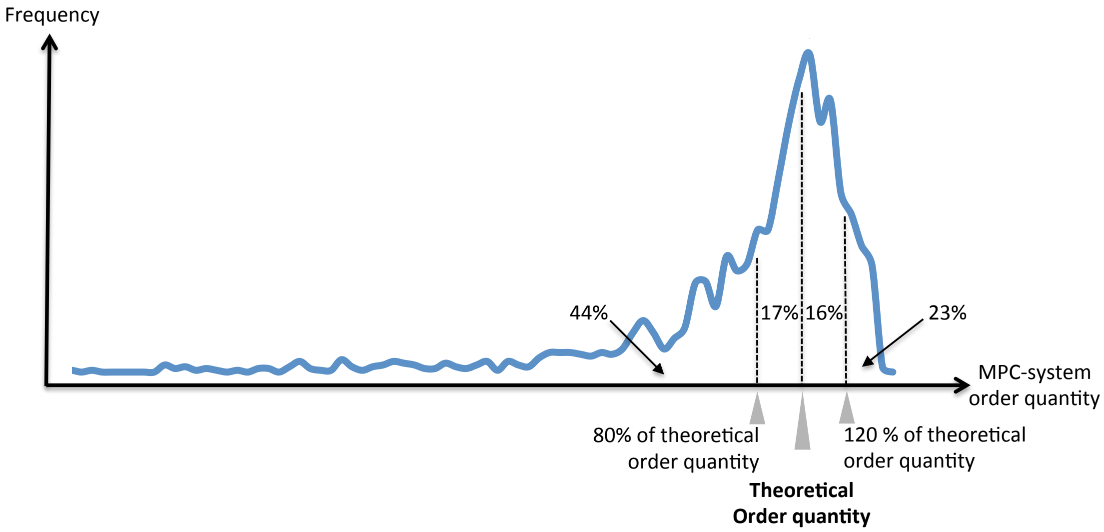


Figure 20. The proportion of MPC-system order quantities that falls within a ± 20% interval from the theoretical order quantity is about 1 out of 3 forecast based articles.

Why these two order quantity measures deviate considerably for most articles is not fully known by UCMSWE. One possible motive is that *MPC-system order quantities* consider non-financial reasons, which in the theory part were exemplified as restrictions in suppliers' manufacturing processes, transportation limitations etc. Interviews conducted at UCMSWE indicated that supplier specific features are important.

Determining the actual order quantity

The third step in the process of determining order quantities is to transform the order quantities from the *MPC-system* to *actual order quantities* sent to UCMSWE's suppliers. Even though the *MPC-system order quantity* is a fix order quantity, the demand in one period can exceed one order quantity and a multiple of orders must be placed. Therefore, *actual order quantities* are not always the same for a specific article. For example, consider a situation where 120 articles are demanded and the *MPC-system order quantity* is 100 articles. Then 200 articles will be ordered, which corresponds to the smallest multiple of orders that can be placed from the *MPC-system order quantity*. If the demand instead is 100, just 100 articles are ordered, i.e. one time the size of the *MPC-system order quantity*. This creates large fluctuations for suppliers upstream and a large increase of inventory levels.

UCMSWE has the impression that this transformation into *actual order quantities* generates redundant stock levels and that additional data could be used to adjust order quantities to the real demand. Ideas from the company include using unit loads as pallets, containers, trucks and restrictions at suppliers as possible data. Instead of increasing the order quantity with a multiple of the *MPC-system order quantity*, only adding a multiple of e.g. pallets until the extra demand is met would be beneficial. Some pilots in this area have been introduced to see how this could be carried out, but since different articles have various characteristics, it has not been considered to be a feasible approach to use for all *forecast based articles*.

4.2.4 Safety buffers

All articles are, according to UCMSWE, considered to have a safety stock but not all have explicitly expressed ones. This chapter discusses the different *safety buffers* that are used today and determines their magnitudes. UCMSWE uses both safety time and safety stock, which both add up to the total *safety buffer*. Independently of whether a *safety buffer* is expressed in time or quantity, it is possible to replace one by the other. To facilitate comparison and to make the total safety effect clearer, safety times are transformed into safety stocks in this research.

UCMSWE is today using a safety time of three days for all its *forecast based articles*, regardless of class. This means that an article has to be delivered to the production site at least three working days ahead of the actual demand of the first article in the delivery. The safety time is not only used due to the risk of late deliveries, but also used by UCMSWE to prepare the material for production. Some articles are kitted before going to production and therefore must be prepared in advance. The three days of safety time result in a *safety buffer* for each period of time, which is explained through figure 12 in chapter 3.6.1.

The trigger for replenishment of class A and B articles is when the *MPC-system* indicates to the responsible material planner that an article will be out of stock in a time equivalent to the *total lead-time* of replenishment. However, the *MPC-system* moves the order three days earlier to get the delivery at least three days before running out of stock, see figure 21.

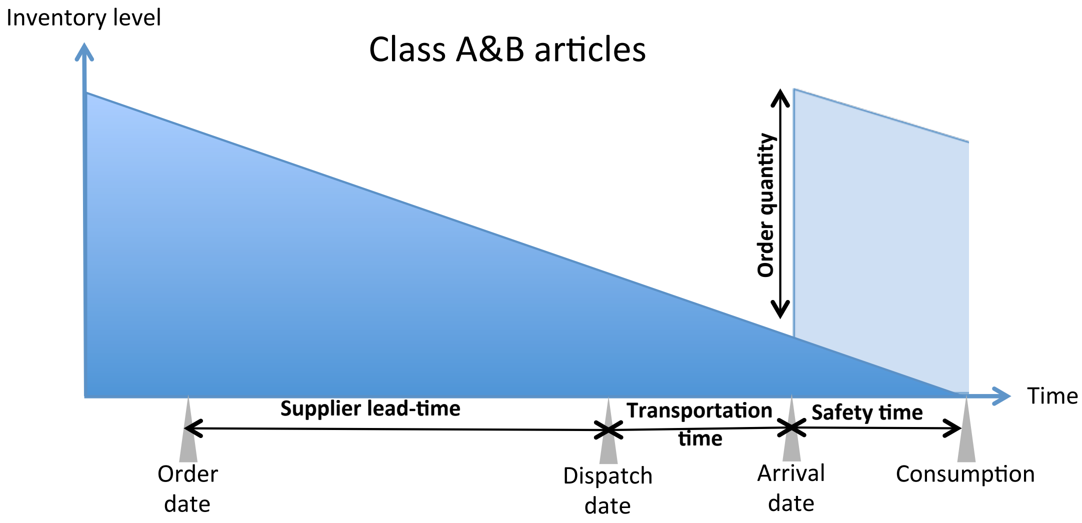


Figure 21. The relation between the inventory level and the time for order placement for class A and B articles with the three days of safety time.

Class C1 and C2 articles have their lowest inventory levels at 8 percent of the articles' annual consumption, according to the ABC-matrix. Anyhow, the *MPC-system* indicates a new order to be delivered three days prior to when the inventory level would shrink below 8 percent of the annual consumption. The effect of this combination of safety time and safety stock is graphically expressed in figure 22. The class based safety stock of 8 percent of the annual consumption is hereafter referred to as *fix safety stock*.

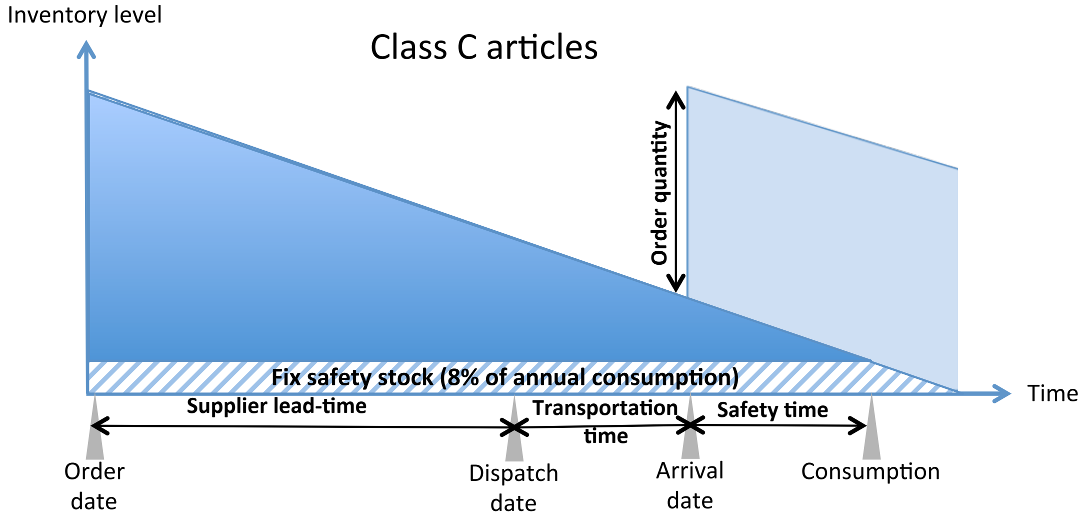


Figure 22. The relation between the inventory level and the time for order placement for class C articles where the three days of safety time is complemented by a fix safety stock of 8 percent of the annual demand.

Even though the main rule indicates that class A and B articles should not have any *fix safety stock* while all class C articles should have, collected data indicates a different situation. Observations show that only 46 percent of all class C articles have a *fix safety stock* and also that 9 percent of all class A and B articles have, without support from the ABC-matrix. 89 percent of all articles with *fix safety stock* are class C articles and 11 percent are located in either class A or class B. If considering the volume value, the ratio between class C and class B is fifty-fifty, see figure 23.

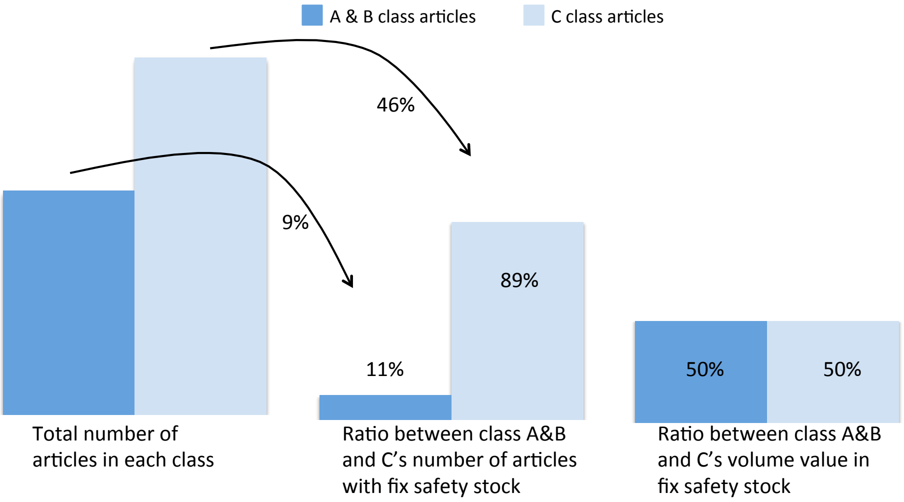


Figure 23. A description of the number and proportion of articles that have fix safety stock at UCMSWE today.

Class A and B articles with *fix safety stock* are all considered by UCMSWE to be exceptions, which can be valid for several reasons. Exceptions may be necessary because of long *total lead-times* (e.g. valid for articles shipped from Asia) or because articles are being phased in or out of production or since considered supplier are currently being changed.

4.2.5 Supplier dispatch dates and delivery windows

The following chapter deals with how supplier dispatch dates and deliveries are organised at UCMSWE. The company uses delivery windows for its suppliers to manage all arriving articles. A supplier's dispatch date is controlled through the delivery window with a time gap equal to the transportation time. This helps UCMSWE to handle received articles with fewer resources compared to if deliveries would have appeared randomly.

The delivery and dispatch schedule at UCMSWE gives 150 suppliers out of 155[3] a single dispatch day per week while only 5 suppliers have two dispatch days per week. Four of the five suppliers with two weekly dispatch dates are important in terms of the volume value of purchased articles but the main reason for their double dispatch dates are due to their bulky goods that would not fit into one shipment. The fifth supplier with double dispatch dates has low volume value and delivers low value articles according to a vendor managed inventory arrangement.

In an inventory level perspective, articles that could have been delivered later the same week are due to the fix dispatch dates forced to be delivered earlier, graphically expressed in figure 24. Therefore, deliveries arrive more than three days prior to consumption as long as the last possible day for delivery does not match with the delivery window.

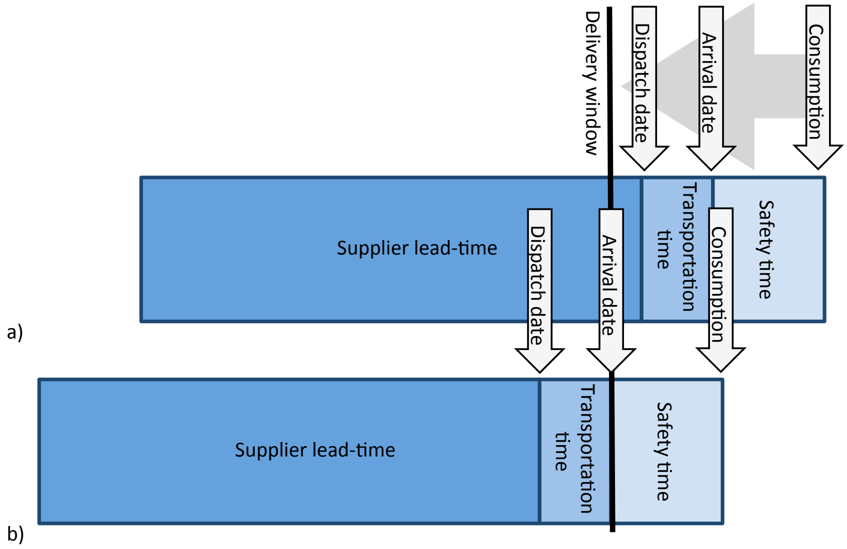


Figure 24. The effect of delivery windows on the inventory levels by forcing the material planners to order earlier (b) than theoretically necessary (a).

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[3] Only the suppliers for the forecast articles are concerned.

With a weekly dispatch date, articles are delivered between three and three plus four days prior to consumption, if only weekdays are considered in the calculations. These once per week dispatch dates correspond to 80 percent of the *forecast based articles'* volume value. The magnitude of the delivery windows' importance for articles' time in inventory is expressed in figure 25. It shows that articles with one weekly delivery window are in risk of more than doubling the minimum safety time.

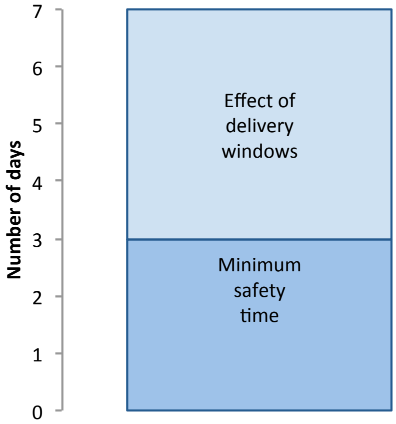

Figure 25. The effect of one delivery window on the inventory level where the number of days in inventory risk to increase from 3 to 7.

Another dimension of delivery windows that generates additional inventory time is holidays that appear on weekdays and thus constitute days where deliveries cannot be done. A delivery that is supposed to be delivered during a weekday holiday instead has to be re-scheduled to a prior delivery window. In 2013, UCMSWE were scheduling for 13 weekday holidays, i.e. 13 weekdays when no deliveries could be done.

4.2.6 Inventory turnover rate and inventory level

As stated in chapter 3.2 the inventory turnover rate is defined as the cost of articles consumed divided by the value of the average inventory, see equation 24. The cost of articles consumed is calculated as the forecasted annual consumption per article multiplied by each article's *standard price* and then added together. Hence the inventory turnover rate is calculated in a production perspective and not in a business controlling perspective. The value of the average inventory is calculated by multiplying the average inventory for an article by its *standard price* and then added together for all articles. The most recently added article's price is used to valuate the inventory, according to the LIFO approach.

$$Inventory\ turnover\ rate = \frac{Cost\ of\ articles\ consumed}{Value\ of average\ inventory} \quad (24)$$

UCMSWE had an inventory turnover rate of 11,6 times per year for the forecasted articles during 2013 and strives to increase the measure in near future. While this work aims to help UCMSWE to reach a higher inventory turnover rate, the cost of articles consumed (turnover) cannot be affected from the scope since the KPI belongs to the sales division.

Instead the value of average inventory is in focus. UCMSWE calculates the inventory turnover rate with samples of the actual inventory level as input data, which is collected every last day of the month. The risk that the samples show an incorrect inventory level exists due to the risk of hitting a level that is at its top or at a very low level, just before a new incoming delivery. The risk is however smaller when looking at numerous articles at the same time since some article fluctuations will cancel each other out. By comparing the total value of the inventory level at each sample date during 2013 with the average value of the inventory, the total sample error was only 0,7 percent. This even though all samples deviated more than the total sample error, see figure 26.

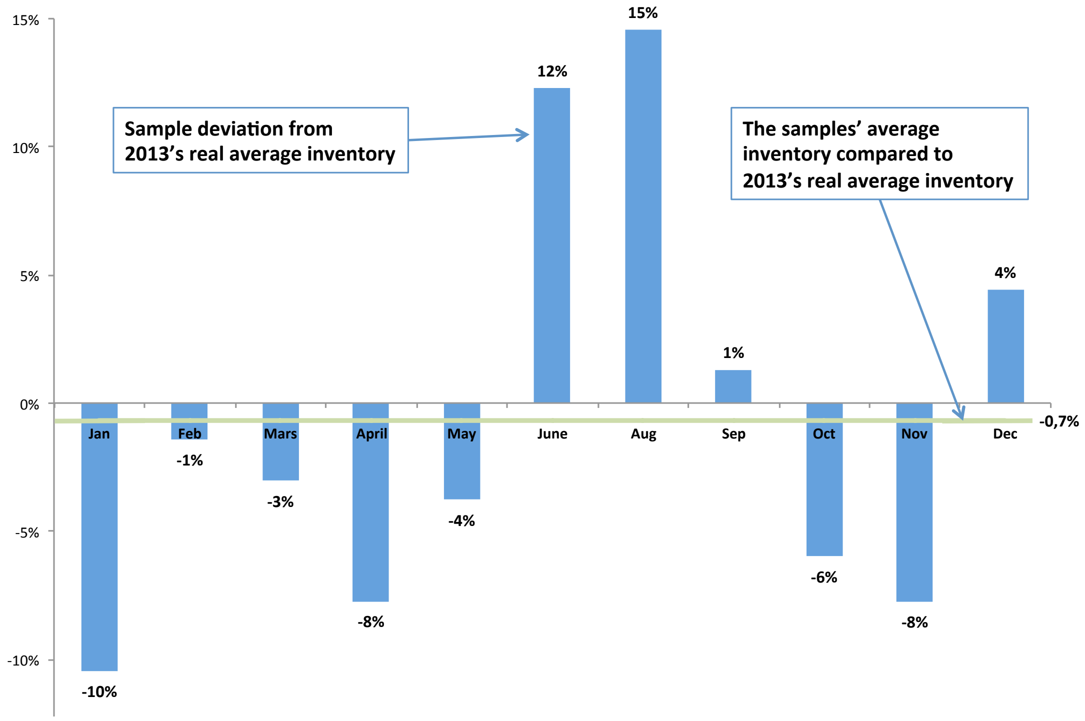

Figure 26. How the value of 2013's inventory level fluctuates around the value of the real average inventory. The line shows the value of the samples' average inventory.

Figure 27 shows the inventory level for a gear that has a high volume value, high consumption and is today classified as an A2 article. The figure shows that the inventory never reaches a lower level than 44 units and has its highest level at 100 units. The *MPC-system order quantity* for this article is 16 units from September 2013 to January 2013, but is changed to 24 units in February 2014. The figure also shows that the *actual order quantity* was twice the *MPC-system order quantity* at two occasions. As could be found in the figure, shortage never appeared for this article during the period.

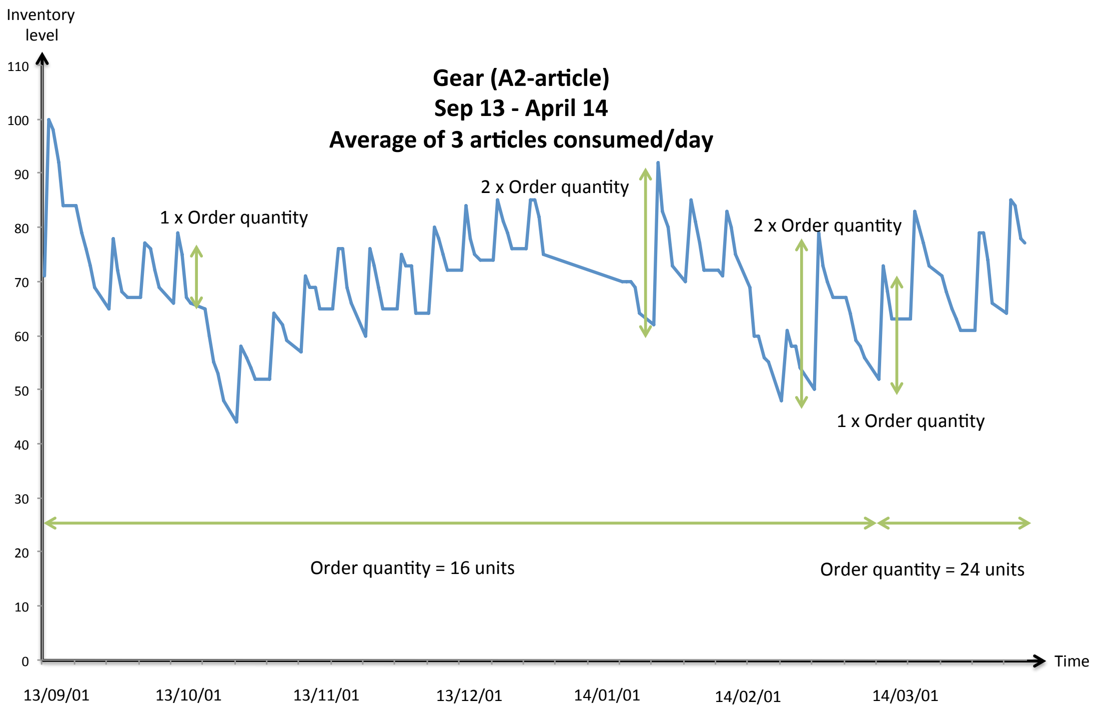

Figure 27. The inventory level during 7 months for an A2 forecast based article.

4.3 Other factors influencing inventory levels at UCMSWE

The previous chapter has described the today's *procurement process* at UCMSWE and the initially identified factors that influence the inventory levels. During the research, it has become clear that these initial factors do not cover the entire reason for the existing high inventory levels at UCMSWE. The empirical findings show that 2013's inventory levels are 3,4 times higher than the inventory levels that the ABC-matrix's order quantities and *safety buffers* would indicate. With this in mind, other factors that would influence the inventory levels at UCMSWE were explored. The first three identified factors in figure 28 are the ones described in the initial model presented in the beginning of the theoretical framework, expressed in figure 2 chapter 3. The other factors from the empirical findings are described briefly in the following chapters without being thoroughly investigated.

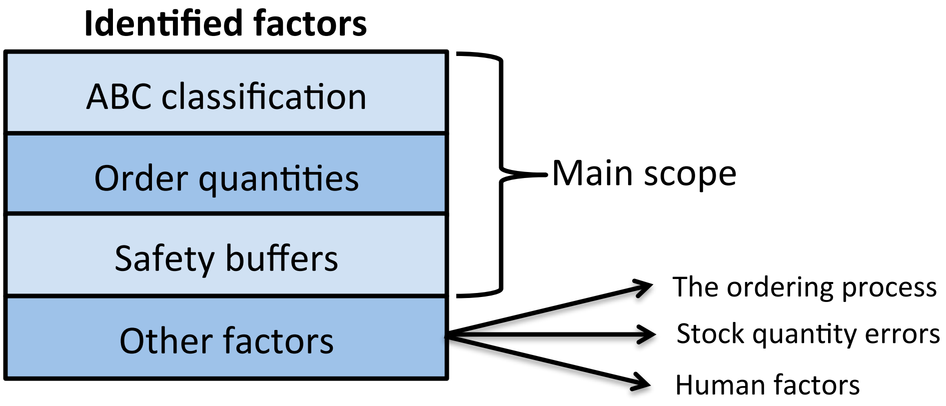

Figure 28. Discovered factors that influence the inventory levels at UCMSWE. The factors are divided into core factors and factors out of the main scope of the thesis.

4.3.1 The ordering process

The material planners are responsible for placing orders of *forecast based articles* to UCMSWE's suppliers. As decision support, they receive proposed order quantities and order dates from the *MPC-system* and these proposals can either directly be confirmed or manually adjusted, as expressed in figure 29. Adjustments are done both to manage internal and external changes and an example is when the material planners bring forward orders prior to the summer and Christmas vacations. The order proposals are adjusted because of uncertainties about when and for how long their suppliers are stopping production during these vacation periods. By ordering larger quantities than needed, UCMSWE creates extra article buffers, which mitigates the risk of running out of stock when ramping up production after the summer and Christmas.

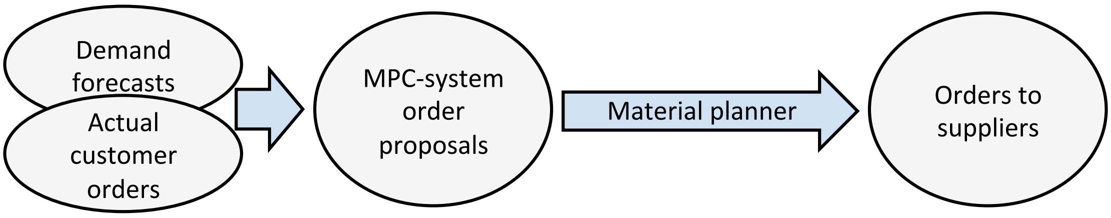

Figure 29. The ordering process at UCMSWE described step-by-step.

The order proposals given to the material planners by the *MPC-system* could be based on real customer orders, forecasted demand or a combination of both. The main strategy in UCMSWE's ordering process is to purchase as much as possible on real customer demand. However, the combinations of long *total lead-times*, short order stock and articles used in an early production phase forces the company to sometimes order articles upon forecasted demand. The demand forecasts are performed on forklift level by UCMSWE's sales department and are thereafter split down by each forklift model's bill of material with a probability for each article depending on how commonly it is included in a model. If an article is included every time a forklift model is manufactured, it gets a 100 percent probability but if there are several alternatives to an article, it gets a probability lower than 100 percent. As with all forecasting, uncertainty is involved and results in a risk of mismatch between the forecasted production and the actual production. After interviews with production and capacity planners at UCMSWE, it has been concluded that the forecasted production has exceeded the actual production lately. Since the *MPC-system* generates order proposal in accordance to the forecasted production plans, a consumption gap of articles between forecasted and actual consumption have been put in inventory, which has increased the inventory levels.

4.3.2 Stock quantity errors

The inventory levels used to calculate the inventory turnover rate are collected directly from the *MPC-system*. Therefore it is important to make sure that the data found in the *MPC-system* is correct and updated. Observations of the day-to-day operations have indicated that errors exist of which two have been identified.

The first identified error is due to backlog in production, which is generated when planned production is behind schedule. Since material planners follow the production plan generated by the *MPC-system,* orders are placed according to it. If the production rate is lower than forecasted, the consumption of inventory is lower than planned and consequently the average inventory levels will be higher. If backlog is a frequent problem in production, orders continue to arrive earlier than necessary and the average inventory levels are continuously high.

The second identified error occurs due to issues in the reporting routines of consumed articles in production. Today each assembler has the responsibility to report all consumption into the system. This is however not performed continuously but instead after an entire batch of articles has been consumed or after a certain number of products have been built. During this delay of reporting, the inventory level in the *MPC-system* differs from the inventory level on the shelf. From observations it has become clear that the reporting sometimes is forgotten and that the system does not know that the articles have been consumed. The *MPC-system* however automatically calculates the articles as consumed when the entire product is complete and ready to ship to the customer. This generates an additional delay in the reporting, which creates a perceived higher inventory level in the *MPC-system* than it actually is. The scale of this error is however not completely investigated.

4.3.3 Human factors

Every time employees are involved in the *procurement process* at UCMSWE, there is a risk of misinterpretation of the situation and suboptimal decision-making. Personal relationships with suppliers and old habits risk influencing decisions to deviate from the predetermined levels or guidelines. The material planners could make own assumptions and for instance order earlier or more to lower the burden of placing many orders or to mitigate the risk of stock deficits. Purchasers can agree upon higher order quantities than necessary due to special agreements or *purchasing price* discounts. Assemblers may forget to report consumed articles to the *MPC-system*. Employees could also feel that the systems or models are not reliable or not good enough to support the reality and therefore chose to deviate from the suggested methods. The *MPC-system* is of course a tool to help managing the *procurement process* in the right direction but it is not always perceived to be accurate.

4.4 Modified model

The empirical findings have concluded that the predefined factors that influence the inventory turnover rate do not give a comprehensive picture of how the inventory levels are affected at UCMSWE. The inventory turnover rate model presented in chapter 3 did not specify any complimentary factors. Anyhow, the empirical findings highlights some probable ones added in the modified model, see figure 30.

UCMSWE’s material planning method generates order proposals partly based on forecasted demand, which has impact in the inventory levels. The material planning method’s structure to only order multiples of the *MPC-system order quantity* also influences the inventory levels. The delivery windows and dispatch dates also have an impact on the inventory levels, together with the gap between production goals and actual production. The lagging reporting routines of consumed articles is another identified factor and for all areas within procurement with human interaction, there is a risk of misinterpretation.

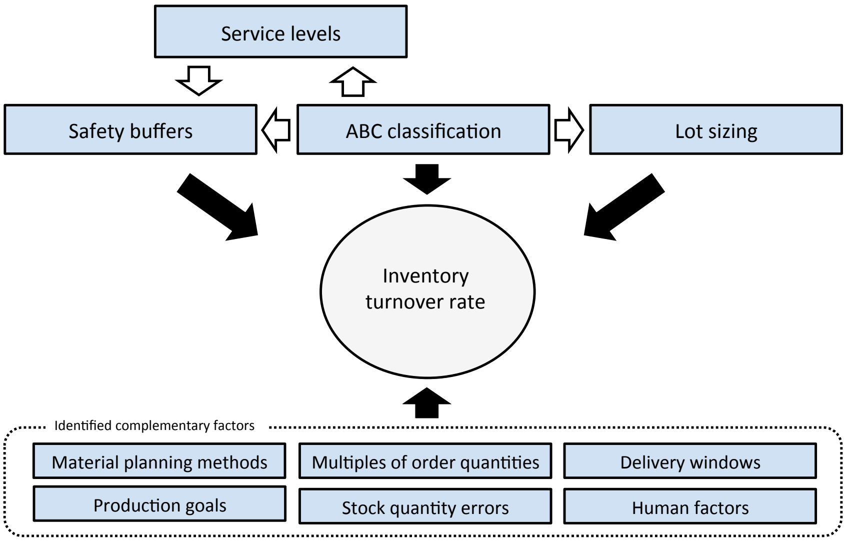

Figure 30. The theoretical model has been expanded through out the empirical findings to include six additional factors.

The modified model presented in figure 30 constitutes the structure for the analysis. The focal areas are presented in the upper part of the figure while the complementary factors below are analysed more briefly.

5 ANALYSIS

The analysis chapter is rooted in the thesis' main purpose: to increase the inventory turnover rate by reducing the inventory levels of *forecast based articles* with consideration to both service level towards production and the *procurement cost* at UCMSWE. Information from the theoretical and empirical studies is used to analyse how to reach the purpose with focus on lot sizing and *safety buffers*.

The first part of the analysis questions whether UCMSWE's current lot sizing method is preferable to enhance the inventory turnover rate or if a more beneficial method to determine order quantity could be structured. The second part of the analysis questions the current method for determining *safety buffers* and how it manages the trade-off between high service level and high inventory turnover rate in an adequate manner. The third and last part analyses potential inventory turnover rate improvements from complementary factors discovered during the empirical research. Graphically expressed, the analysis questions the modified model presented in figure 30 chapter 4.4.

5.1 Part 1: Questioning the lot sizing method

The analysis about the lot sizing method at UCMSWE considers the current model to determine order quantities. The lot sizing method includes input data in terms of volume value and consumption and uses the ABC-matrix as a tool to transform the input data to output. The output data is defined as article class based order frequencies and indirectly article class based order quantities, see figure 31.

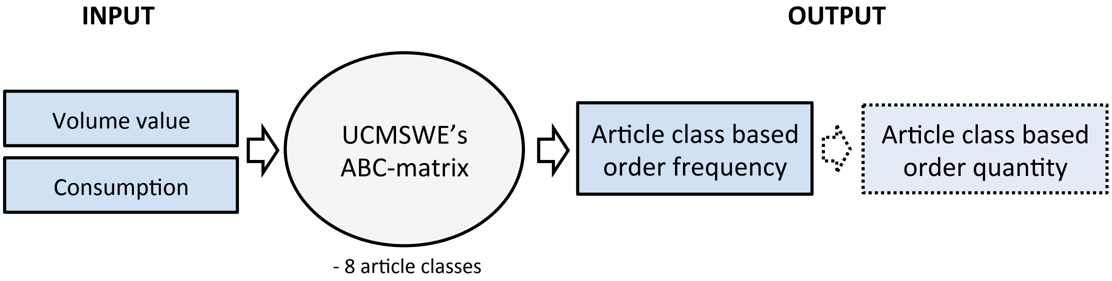

Figure 31. The figure shows how ordering quantities currently are determined and their relation to UCMSWE's ABC-matrix. Input data to the ABC-matrix is also described in the figure.

Three questions have been stated with consideration to the model presented above, which all are answered in the first part of the analysis.

- Is the current lot sizing model providing output data with the right level of detail?
- Is an ABC-matrix the right tool to generate order frequency and indirectly order quantity data?
- How could the current lot sizing method be changed to achieve a higher inventory turnover rate?

When analysing UCMSWE's lot sizing method, a few definitions have been stated. These definitions are primarily used when the results of the analysis are presented in the end of the chapter. (1) The best inventory level with the ABC method is the inventory simulated solely by the order quantities and *safety buffers* generated by the ABC-matrix. (2) The best inventory level with the EOQ method is the inventory when the order quantities are generated by the Wilson formula instead of with the ABC-matrix. (3) The real inventory level with the ABC method is the actual inventory level at the company, derived from 2013's transaction data. (4) The estimated inventory level with the EOQ method is the estimated inventory level when EOQ is used.

5.1.1 Level of details

There is a trade-off concerning the level of detail and the resources consumed when determining order frequencies and order quantities. One extreme is to treat all articles the same and the other extreme is to treat each article after its unique characteristics. As described in the empirical findings, UCMSWE has chosen a middle way where its *forecast based articles* are treated according to principles set for eight different article classes in an ABC-matrix. This approach makes the procurement rather easy to run since its ABC-matrix, expressed in table 6 chapter 4.2.2, alone is a sufficient base to determine order quantities for the articles. Thus, using an ABC-matrix consumes relatively small resources in terms of material planning and purchasing activities, as well as in terms of computation power. Another reason for UCMSWE to use a lower level of detail is that the *theoretical order quantity* does not constitute the final quantity, but just a guideline to generate the *MPC-system order quantity* and consequently also the *actual order quantity*. Additionally, as examined theory emphasises, the total cost curve is flat around the economically most preferable order frequency or order quantity and deviation is therefore less costly around the optimal level, see figure 11 chapter 3.4.4.

For an ABC-matrix to efficiently determine order quantities, there should be well-defined groups of articles that share certain characterises. When plotting the *forecast based articles* with the ABC-matrix's two *inventory policy measures* (consumption and volume value), it is difficult to find well-defined article groups as figure 32 shows.

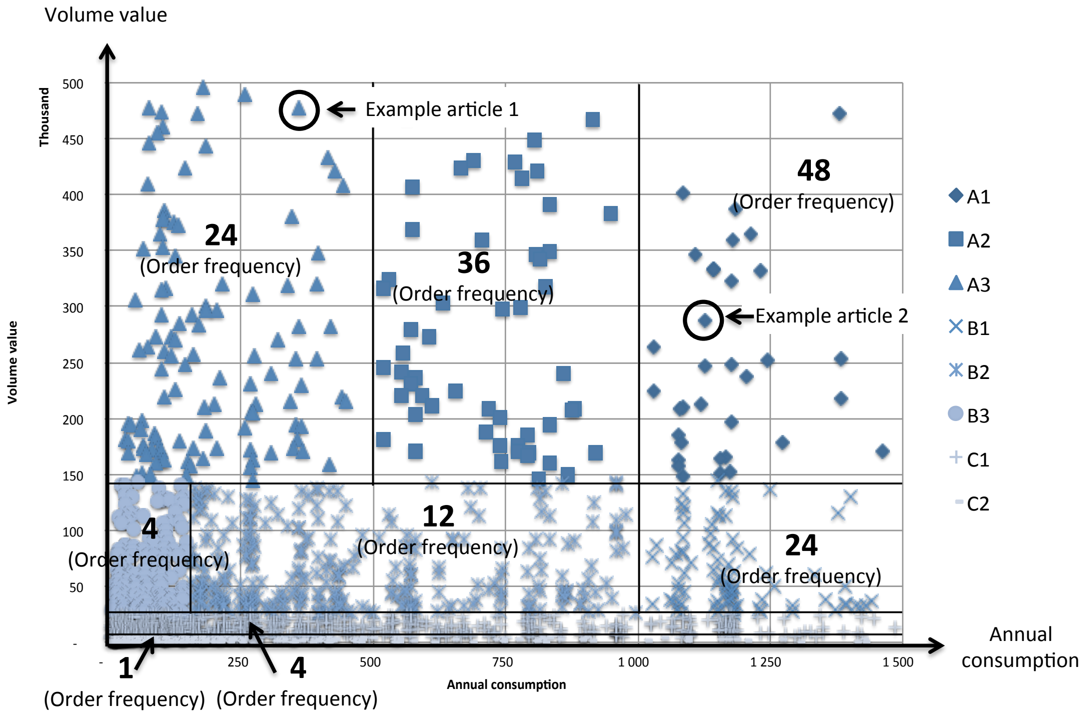

Figure 32. A plot of UCMSWE's forecast based articles with relation to consumption and volume value. A small amount of article has been left outside the plot because of too extreme volume values or consumptions. The numbers in the plot indicate the number of times each article should be ordered each year.

The plot has been analysed critically and it has been asked whether chosen *inventory policy measures* are relevant when looking for defined groups of articles. While the volume value directly drives inventory costs, the annual consumption does not. The annual consumption factor is instead believed to generate a sub-optimised structure when used as an *inventory policy measure*. With the aim to increase UCMSWE's inventory turnover rate by lowering the value of the company's inventory, it is counterproductive to have higher ordering frequencies for some low volume value articles than for some high volume value ones. To exemplify, example article 2 is ordered twice as often as example article 1 (48 compared to 24 times annually) even though example article 2 has a considerably lower volume value.

To prove the relationship between employed capital in inventory and volume value, the formula for average employed capital has been derived from equation 1 chapter 3.1. Equation 1 states that the average inventory is equal to the safety stock plus half of the order quantity. Based on this relation, the average employed capital in inventory is defined as the average inventory level multiplied by the article's price, equation 25.

$$Average\ employed\ capital\ = \left(Safety\ stock + \frac{Order\ quantity}{2}\right) \times Price \quad (25)$$

Since the aim has been to find a direct relation between the average employed capital in inventory and the volume value, the annual consumption has been introduced in relation to the order quantity, see equation 26.

$$Order\ quantity = \frac{Annual\ consumption}{Order\ frequency} \quad (26)$$

Since the volume value is defined as the consumption multiplied by the price, a direct relation between employed capital in inventory and volume value is found by inserting equation 26 into equation 25. This relation is expressed in equation 27. As seen in the equation, a higher volume value gives more employed capital as long as the order frequency is constant. Since all articles in a class have a common order frequency but different volume values, they employ different amounts of capital. At the same time, articles with the same volume values could have different order frequencies according to their article classes and therefore employ different amounts of capital. Simultaneously, the factor consisting of safety stock and price is independent of the volume value.

$$Average\ employed\ capital = \ Safety\ stock \times Price + \frac{Volume\ value}{2 \times Order\ frequency} \quad (27)$$

If UCMSWE was obligated to use an ABC-matrix to determine order quantities, it would in the context of inventory turnover rate make more sense to solely define the article classes by volume value. Even with a pure volume value segmentation of UCMSWE's *forecast based articles*, there would be a considerable article spread in each class why it is found valuable to also examine UCMSWE's other options regarding the level of detail. One extreme, to treat more than 3'000 *forecast based articles* in the same way with the same order quantity or frequency is not believed to be realistic due to the widely spread article characteristics. By instead looking in the other direction, to increase the level of detail, more efficient lot sizing could be reached if the right data is accessible. A quantifying analysis about the potential to increase the inventory turnover rate by using article specific order quantities follows.

5.1.2 Article specific order quantities

Article specific order quantities can be managed with different lot sizing methods. Considering UCMSWE's resource constraints regarding computation power and the number of material planners and purchasers, dynamic lot sizing methods are believed to be too heavy to implement. Left with semi-dynamic lot sizing methods, both ERT and EOQ constitute feasible approaches. Since UCMSWE's *MPC-system* works with quantities, EOQ is believed to be more efficient to use and has been the core of this analysis part. As described in the theory, EOQ calculations are based on the Wilson formula and require information about the consumption per time unit, price per article, inventory-carrying factor and ordering cost, expressed in figure 33.

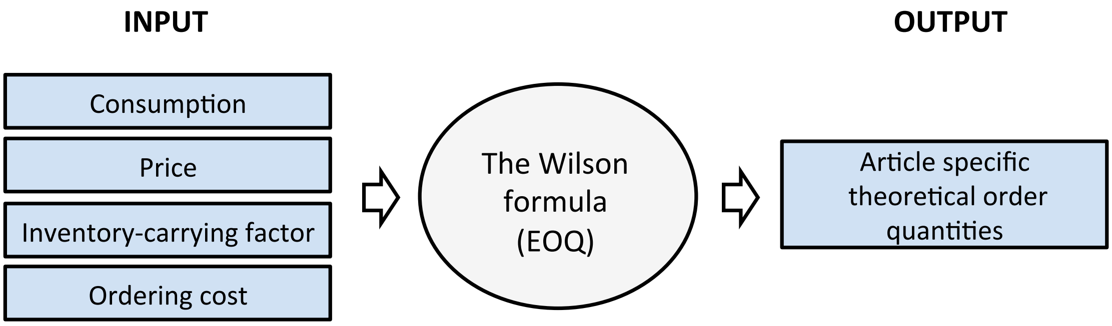

Figure 33. The structure of how to determine article specific order quantities with the Wilson formula.

Consumption per time unit

UCMSWE already uses forecasts to plan its production and these forecasts provide relevant data to estimate the consumption per time unit, i.e. annual consumption. These forecasts are updated four times per year and express future consumption on article level. Further, the company perceives its consumption forecast errors to be acceptable.

Price per article

The price per article is also a parameter that UCMSWE has easy access to. Anyhow, a price in this context is a bit more complicated to calculate than first thought. The price parameter is defined as the *purchasing price* multiplied by a standard price factor, i.e. the *standard price*. The standard price factor is today the same for all articles and consists of two components: a transportation surcharge and an administration and material surcharge, see equation 28. The administrative and material surcharge is assumed to be constant for all orders as a percentage of the total order value, while the transportation surcharge is believed be more volatile depending on which supplier the articles are sent from. Thus, to find a fair standard price factor per article, it is reasonable to consider characteristics of the supplier from whom the articles were shipped.

$$Standard\ price\ factor(\%) = \\ Transportation\ surcharge + Administration\ and\ material\ surcharge \quad (28)$$

The aim has been to understand how to consider transportation costs in an easily managed way. Adding real transportation costs instead of a surcharge to each order would result in the most correct allocation of transportation costs, but would also result in much extra work. Instead, data from 2013 regarding the actual transportation cost per supplier, the volume value per supplier and the number of transportation days for each supplier have been analysed to find an alternative approach to calculate the standard price factor. To better understand how effective the transportation surcharge is today, the first test was to find the correlation between the transportation surcharge multiplied by each supplier's volume value compared to the actual transportation cost for the supplier during 2013. A correlation reaches from minus one to one and is as strongest at its extreme values. This analysis indicated a strong correlation of 0,83, see equation 29.

$$TS \times VV_s \leftrightarrow TC_s \rightarrow Correlation = 0{,}83 \ (29)$$

Notations for equation 29-34:

MTS = *Modified transportation surcharge*
TS = *Transportation surcharge*
TC_S = *Transportation cost per supplier*
VV_S = *Volume value per supplier*

Since the transportation surcharge is expressed as a fix percentage, the correlation is not affected by it and the transportation surcharge could therefore be removed without changing the correlation. The correlation between the volume value per supplier and the transportation cost per supplier is expressed in equation 30.

$$VV_s \leftrightarrow TC_s \rightarrow Correlation = 0{,}83 \ (30)$$

Another tested correlation is the relation between the number of transportation days from UCMSWE to its supplier and the supplier's transportation cost. The correlation between the number of transportation days and the actual transportation cost was unfortunately low, which is why this approach has not been further analysed.

A third correlation was tested by taking the volume value per supplier in power of two and compared the ratio to the transportation cost. The correlation between these two strings of data was even stronger with a value of 0,89, equation 31.

$$VV_s^2 \leftrightarrow TC_s \rightarrow Correlation = 0{,}89 \ (31)$$

Since the volume value per supplier in power of two has a greater correlation than the current method, it would result in a more correct transportation surcharge to calculate the *standard price.* Anyhow, even though the correlation is stronger, the data strings are not equal in size. With the same logic as was shown in equation 29 and equation 30, a constant could be added to one of the data strings without affecting the correlation. Therefore a new percent factor referred to as the modified transportation surcharge was added to the correlation expression, see equation 32.

$$VV_s^2 \times MTS \leftrightarrow TC_s \rightarrow Correlation = 0{,}89 \ (32)$$

The expression to the left in equation 32 is not usable without calibration of the total transportation cost added with the surcharge to correspond to the actual total transportation cost. Therefore the volume values per supplier in power of two were summed and multiplied by modified transportation surcharge and set equal to the actual total transportation cost, equation 33.

$$MTS \times \sum VV_s^2 = \sum TC_s \ (33)$$

The equation is solved for the modified transportation surcharge to find a fix percentage, see equation 34.

$$MTS = \frac{\sum TC_s}{\sum {VV_s}^2} \ (34)$$

When the modified transportation surcharge has been determined, it also has to be integrated to the total surcharge, i.e. a modified standard price factor. The standard price factor's second component, the administration and material surcharge has been assumed to remain constant as a percentage of the supplier volume value. There is a conflict of having the two parts of the modified standard price factor with different units. Thus, the modified transportation surcharge is multiplied by the volume value per supplier to get the same unit as the administration and material surcharge, equation 35.

$$Dynamic\ transportation\ surcharge\ (\%)\ = VV_s \times MTS\ (35)$$

The dynamic transportation surcharge does together with the administration and material surcharge constitute the modified standard price factor's final parts, expressed in equation 36. The modified *standard price* is computable by multiplying the *purchasing price* for an article and the modified standard price factor for the supplier together.

$$Modified\ standard\ price\ factor\ (\%) =$$
$$Dynamic\ transportation\ surcharge + Administration\ and\ material\ surcharge\ (36)$$

Inventory-carrying factor

The inventory-carrying factor does not exist as an available data parameter at UCMSWE today, why a more thorough analysis has been performed to find the parameter value. As theory states, the inventory-carrying factor consists of the cost of capital, handling costs and risk costs. It can be determined in three different conceptual ways: by policy, calculation or benchmarking.

The standpoint has been that a calculated inventory-carrying factor is superior to a policy-based or benchmark-based one when reliable data to support the calculation is accessible. While a policy based inventory-carrying factor should be used to reach a quantified goal and benchmarking should be used to validate set inventory-carrying factor levels, a calculated level considers a company's and its articles' unique characteristics. Thus, focus has been to calculate an appropriate inventory-carrying factor for UCMSWE, which has been validated through benchmarking with both theory and industry levels. Theoretical models cannot always be applied to real cases instantly and sometimes have to be adjusted to fit reality. Hence, it has been asked whether all three cost components (capital, risk and handling) are relevant when calculating UCMSWE's inventory-carrying factor.

The cost of capital, which according to examined theory often is dominant, is a component that has to be considered. The capital cost is proposed to be calculated from the Swedish 10-year policy rate of 2 percent, on which a risk premium is added. The risk premium is supposed to reflect an investor's risk associated with lending to the business. As discussed in the theory part, a premium's size depends on the perceived risk associated with the investment and benchmarking is necessary to find a trustworthy cost of capital level.

Benchmarking with cost of capital-tables compiled by Standard & Poor's capital IQ, Bloomberg and the Federal Reserve indicates that an average company in the auto and truck industry has cost of capital of 8 percent in 2014. At the same time, US 10-year government bonds are traded at 2,75 percent. Thus the risk premium is estimated to be around 5 percent. To adjust the cost of capital to the Swedish economic environment, the Swedish 10-year government bond has been used to set the risk free rate, as seen in table 7. The cost of capital for UCMSWE is estimated to approximately 7 percent.

Table 7. A calculation of the cost of capital for UCMSWE.

Cost of capital	
Swedish 10-year government bond	2%
Risk premium	5%
Total	**7%**

In addition to the cost of capital, theory states handling costs and risk costs as cost elements to be consider when calculating the inventory-carrying factor. UCMSWE supposes its ordering costs to be independent of how much the company orders each time and instead to be dependent on the total order amount. Risk costs, which include scrapping and insurance costs are perceived to be important and are taken into consideration. Adding the cost components together, the inventory-carrying factor at UCMSWE is calculated to approximately 9 percent, see equation 37.

$$Inventory - carrying\ factor = 7\% + \frac{Risk\ costs}{Value\ of\ average\ inventory} = 9\% \quad (37)$$

Ordering cost

When determining the ordering cost, it has to be decided whether to use a top-down approach or to apply a bottom-up approach. While a bottom-up strategy measures the ordering cost for each order line and then scales up the cost per order line, a top-down approach handles uncertainties in a better way by starting with overall resources allocated to handle orders.

A top-down approach is thus proposed to determine the ordering costs at UCMSWE. Information about the amount of resources that UCMSWE allocates to handle procurement of *forecast based articles* has been the main source of information. With the number of material planners working with the *forecast based articles*, the number of working days per year, the number of hours per working day, the percentage of the working time allocated to purchase *forecast based articles*, the hourly rate and the number of annual order lines, the ordering cost can be calculated. The calculation structure is presented in figure 34. The calculated ordering cost is 48 SEK, which is based on the resource allocation with the current procurement method. Anyhow, the ordering cost is supposed to be the same with the proposed EOQ method as with the current ABC-based method.

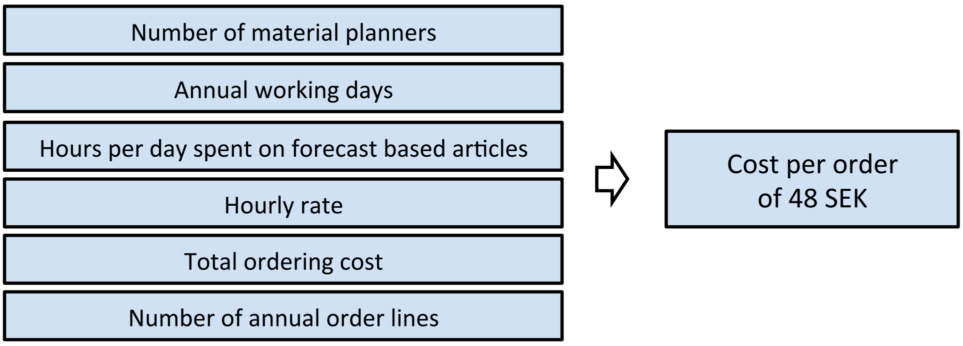

Figure 34. The top-down approach that has been used to estimate the ordering costs.

5.1.3 Results – Lot sizing methods

A lot sizing method that considers each *forecast based article's* unique characteristics is proposed to UCMSWE in its efforts to increase the inventory turnover rate. The presented method determines order quantities with EOQ calculations considering the consumption, the price, the inventory-carrying factor and the ordering cost, see figure 35. The price component, which includes inbound transportation costs, will be dynamic and consider the supplier's characteristics.

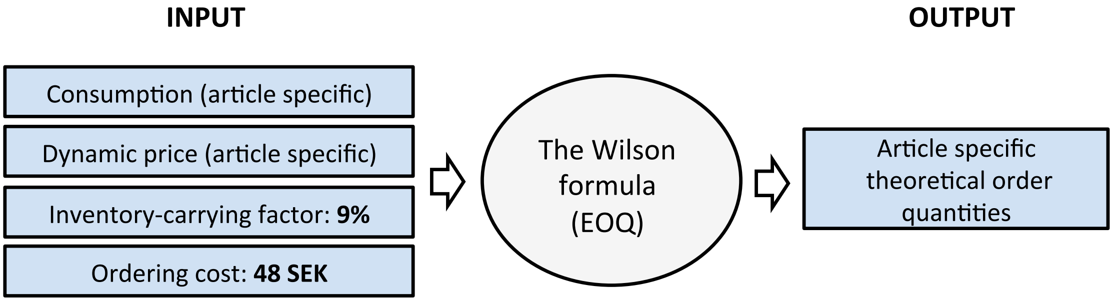

Figure 35. The structure of how to determine article specific order quantities with the Wilson formula.

The standpoint in the evaluation of how much the inventory turnover rate can be improved by changing lot sizing method is based on how much the employed capital can be reduced. The best inventory level with the ABC method and the best inventory level with the proposed EOQ method is compared, see figure 36. The real inventory level with the ABC method is a measure computed from the 2013's transaction data and gives an indication of how far away from the best inventory level at UCMSWE is today.

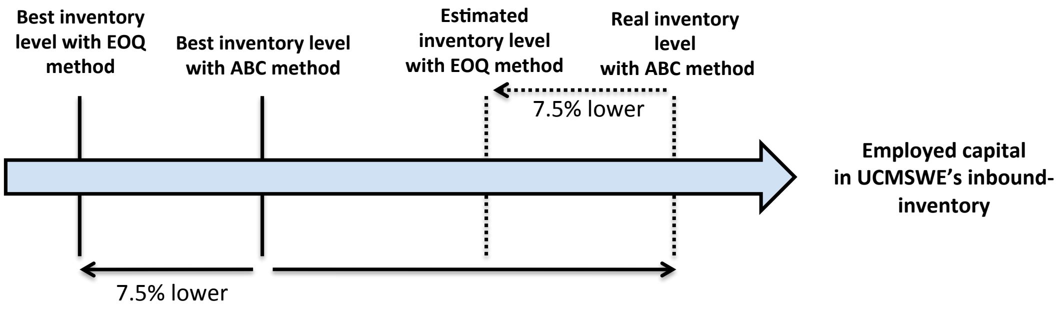

Figure 36. The reduction of employed capital between the best inventory level with the ABC method and the proposed EOQ method is estimated to 7,5 %.

Simulations of collected data from the empirical findings indicate a 7,5 percent reduction of employed capital in the inbound-inventory. The reduction would, ceteris paribus, increase the inventory turnover rate from 11,6 to 12,5 annual turns, equation 38.

$$Inventory\ turnover\ rate = \frac{11{,}6\ (today)}{100\% - 7{,}5\%} = 12{,}5\ (38)$$

However, with an unconditional strive for higher inventory turnover rate, one can just order smaller order quantities, which automatically gives less employed capital. The proposed solution thus has to be proven financially sound as well to be potentially successful. For example, ordering lot-by-lot would result in close to zero inventories but result in extensive costs for transportation and to manage the ordering process. The validation of the proposed model's financial soundness is performed through a comparison of employed capital together with ordering costs. As seen in table 8 the proposed EOQ model gives both lower employed capital and less ordering costs.

Table 8. The proposed EOQ method reduces the employed capital with 7,5% and ordering costs with 27%.

	Best inventory level with ABC model	➔	Best inventory level with EOQ model
Employed capital:	100%	➔	92,5%
Ordering costs:	100%	➔	73%

Lower total ordering costs is a result of increasing the average order quantity. With 27 percent less orders to place with the proposed method, it can assumed that

UCMSWE's material planners would consume less time to manage the *forecast based articles* and instead take more responsibility in other areas. Anyhow, it would probably result in a workload drop smaller than 27 percent since all supplier relationships still have to be managed.

5.2 Part 2: Questioning the safety buffer method

The second part of the analysis examines UCMSWE's current method for *safety buffer* determination, illustrated in figure 37. The *safety buffer* method includes input data in terms of volume value and consumption and uses the ABC-matrix as a tool to transform the input data to output. The output is a *safety buffer* is either three days of safety time or three days of safety time plus eight percent of the annual consumption, dependent on the article class.

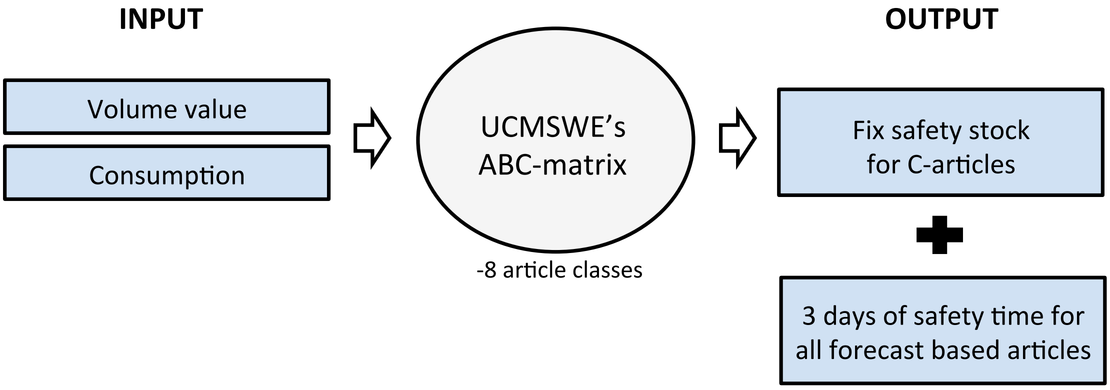

Figure 37. The figure shows how the safety buffers currently are determined and their relation to UCMSWE's ABC-matrix. Input data to and output data from the ABC-matrix is also described.

Three questions have been stated with consideration to the model presented above, which all are answered in the analysis.

- Is the current *safety buffer* method providing output data with the right level of detail?
- Could an ABC-matrix be used to generate *safety buffer* levels?
- How can the trade-off between capital employed and service level be managed?

When analysing UCMSWE's *safety buffer* method, two definitions have been stated and used throughout the analysis: (1) the best *safety buffer* with the ABC method and (2) the real *safety buffer* with the ABC method. The best *safety buffer* with the ABC method is the *safety buffer* generated if all class A and class B articles solely have three days of safety time while class C articles solely have 21 days of safety time. The real inventory level with the ABC method is calculated from the real average inventory for each article minus half of the article's order quantity, derived from equation 1 chapter 3.1.

5.2.1 Questioning the level of detail in output of safety buffer

As with lot sizing, there is an trade-off concerning the level of detail for output data and the resources consumed where the extremes goes from treating all articles the same to treating each article according to its unique characteristics. With detailed data, a company could reach more optimal inventory levels but would simultaneously consume a considerable amount of recourses to manage the data. With less detailed data, the inventory levels risk to be far from optimal. Examined theory emphasises that using the same *safety buffer* for all articles risk to create high capital employed with low average service level. This could on the other hand be offset by less need for resources to manage the article data.

The empirical findings show that UCMSWE handles the *safety buffers* for its *forecast based articles* on a high level, only separating them in two different ways. Class A and class B articles only get three days of safety time as *safety buffer* whereas class C articles also receive eight percent of their annual demand in a *fix safety stock*.

UCMSWE's way of determining *safety buffers* today is easy for the employees to understand and does not require extensive calculations or great efforts from the purchasing and logistics division. At the same time, to handle more than 3'000 unique articles in just two different ways can impossibly generate optimal inventory levels for a majority of the concerned articles. Especially with consideration to that only 46 percent of the class C articles are left with a *fix safety stock* and 9 percent of the class A and class B articles are handled as special cases with *fix safety stocks,* the current method's efficiency is questioned. The difference in volume values between the articles further strengthens the probability that the current model is insufficient to provide both high inventory turnover rate and sufficient service levels toward production. As a result, one could assume UCMSWE to face too low service levels for a considerable amount of its articles. Anyhow, the presences of other influencing factors that fall outside the scope of this research (the complimentary factors) are currently preventing extensive inventory stock-out issues.

Before it is possible to describe the current service level performance, a definition has to be established. The original fill rate-measure is believed to be the most practical choice of service level since it is both easy to understand and widely used by other companies and literature, which facilitates benchmarking. The modified versions of fill rate: value fill rate and order line fill rate are also easy to conceptually understand, but less frequently used in literature and thus more difficult to benchmark. The relation between these service level measures is described in figure 38, with the chosen fill rate in bold letters.

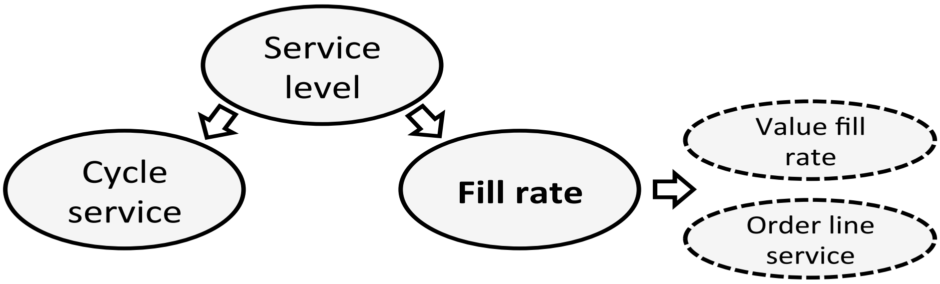

Figure 38. The relation between examined service level-measures.

The fill rate is calculated by solving the fill rate from equation 18 chapter 3.6.2 and using equation 16's assumption of no lead-time variations, see equation 39.

$$Fill\ rate\ level = 1 - \frac{E(z) \times \left(\sigma_D \times \sqrt{LT}\right)}{Q} \quad (39)$$

Notations for equation 39:
$E(z)$ = *Service loss function*
LT = *Average lead-time in time periods from order to delivery*
Q = *Average order quantity*
σ_D = *Standard deviation of demand during the time period*

With the best *safety buffer* with the ABC method, class A and class B articles obtain insufficient average fill rates. The below example shows a simulation based on empirical findings and describes the theoretically obtained average fill rates the company obtains with solely three days of safety time for class A and class B articles. Even though a majority of the class A and class B articles obtain high fill rates of more than 95 percent, a non-negligible amount of articles have dangerously low fill rates, as seen in figure 39.

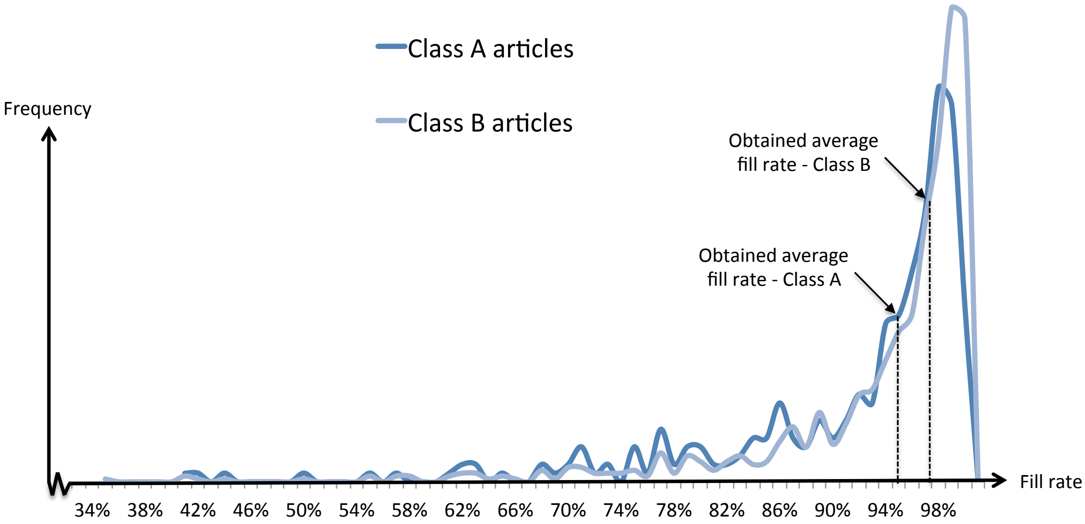

Figure 39. Obtained fill rates for class A and class B articles with the best safety buffer with ABC method. This corresponds to solely three days of safety time.

At the same time, almost all class C articles have a fill rate of 99 percent or higher. The main reason for exceeding the class A and B articles is the *fix safety stock* that is added to the three days of safety time, which corresponds to another 18 days of safety time, see equation 40[4].

$$Fix\ safety\ stock = 8\% \times 220\ days\ of\ production = 17{,}6\ days \quad (40)$$

With a total of almost 21 days of safety time, the class C articles' fill rates are plotted in figure 40.

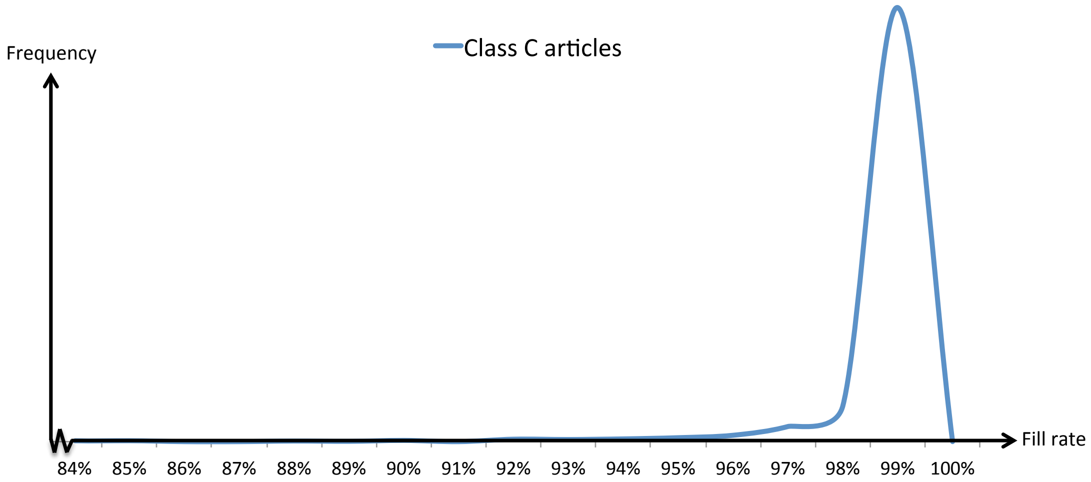

Figure 40. Obtained fill rates for class C articles with the best safety buffer with ABC method. This corresponds to solely 21 days of safety time.

In light of the examples of fill rate spreads above, UCMSWE's efforts to introduce *fix safety stocks* for a considerable amount of class A and B articles are understandable, as well as the efforts to remove *fix safety stocks* from some class C articles. Anyhow, this does not follow the ABC-matrix's framework for *fix safety stocks*, i.e. only 46 percent of C articles and 91 percent of A and B articles follow the framework. Hence, doubts increased whether the current *safety buffer* method is resource efficient when that many articles' *safety buffers* have to be manually adjusted. It is thus believed that UCMSWE could increase its level of detail to determine *safety buffers* with currently allocated resources.

To be able to compare best *safety buffer* with the ABC method and alternative approaches, the employed capital in *safety buffers* is calculated for each alternative. The obtained average fill rate for each article class is also calculated to be able to evaluate the examined approaches, see table 9.

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[4] Derived in Appendix 6

Table 9. The results in terms of safety times and obtained average fill rates with the best safety buffer with ABC method.

Best safety buffer with ABC method		
Article class	**Safety time**	**Obtained average fill rate**
Class A	3 Days	95,6%
Class B	3 Days	97,9%
Class C	21 Days	100%

5.2.2 Redefining article classes and safety buffers

As already emphasised, the current use of annual consumption as *inventory policy measure* does not group the *forecast based articles* in an optimal way with consideration to the inventory turnover rate. With only one relevant *inventory policy measure* left (the volume value), eight article classes are considered to be too many in an ABC-matrix. Based on ABC classification theory examined in chapter 3.3, the use of only three article classes is proposed with fill rate as *control parameter*, see figure 41.

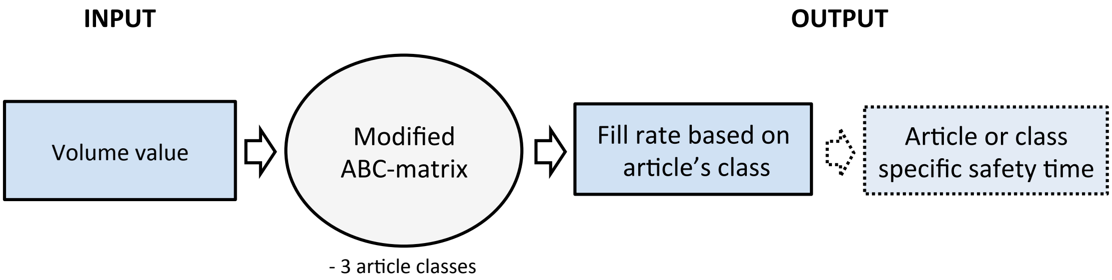

Figure 41. The modified method to calculate safety buffers for UCMSWE's forecast based articles.

The modified ABC-matrix uses three fill rates that are derived from examined literature: 95 percent for class A, 97 percent for class B and 99 percent for class C, expressed in table 10. The three article classes keep the currently used volume value intervals and a Pareto distribution between the three classes are hence maintained, where 10 percent of the articles correspond to almost 80 percent of the total volume value. 20 percent of the articles are placed in class B and 70 percent in class C. How the volume value is used as an *inventory policy measure* to define the article classes and proposed *control parameter* is also described in table 10.

Table 10. The modified ABC-matrix with only three article classes uses the same volume value boundaries for article categorisation. Fill rate is the proposed control parameter.

Category	**Volume value (T SEK)**	**Service level (Fill rate)**
A	> 145	95%
B	25 – 145	97%
C	< 25	99%

UCMSWE's current *safety buffer* output data concerns both safety stocks and safety times, see figure 37. As discussed in the theoretical framework, safety times and safety stocks are strongly related, why the advantage of keeping both *safety buffer* measures have been questioned. Based on the fact that UCMSWE's *MPC-system* already works with safety times for all *forecast based articles*, a time based *safety buffer* is proposed to be kept while used safety stocks are suggested to be transformed.

With proposed redefinitions of article classes and *safety buffers*, two possible approaches of how to work with *safety buffers* are analysed, where both approaches use fill rates set for each article class. One approach aims to achieve an average fill rate in each class with as few days of safety time as possible. The other approach aims to achieve the same fill rate for all articles in a class.

Approach 1: Fix safety times and individual fill rates

The first considered approach uses the three fill rates (95, 97 and 99 percent), derived from the modified ABC-matrix. These fill rates are transformed into safety times so that an entire class have a common safety time. The only constraint for each article class is that the obtained average fill rate matches the predetermined fill rate set by the modified ABC-matrix. This is done through simulations where the safety time is found to be equal to 2,3 days for class A, 1 day for class B and 2,7 days for class C. These safety times have been rounded up to the closest integer, i.e. 3 days, 1 day and 3 days, to create more manageable input data to the *MPC-system*. To not interfere with the kitting activities of some *forecast based articles* prior to production, UCMSWE has requested a minimum of 2 days of safety time. Hence, the obtained average fill rates are higher than initially set, which is seen in table 11. Table 11 also shows the change in capital employed in *safety buffer*, which has been reduced considerably compared to the best *safety buffer* with the ABC method.

Table 11. The results in terms of employed capital, safety times and obtained average fill rates. The results are compared to UCMSWE's best performance with the ABC method.

Approach 1: Fix safety times and individual fill rates		
Article class	**Safety time**	**Obtained average fill rate**
Class A	3 Days	96,2%
Class B	2 Day	98,0%
Class C	3 Days	99,2%
Total change in capital employed in safety buffer:		**-26%**

By using this class-based approach to define safety times, the spread of fill rates is still considerable. Even though the average obtained fill rates meet the predetermined levels from the modified ABC-matrix, the lowest fill rates for each class are at very low levels and could therefore constitute a problem area. An example of the structure of how the articles in one class receive their individual fill rates is expressed with the trade-off between *safety buffer* and fill rate in figure 42.

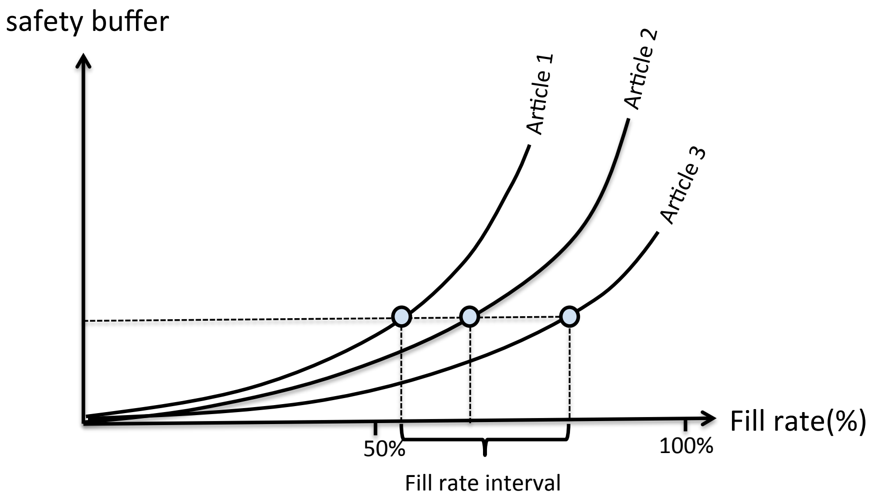

Figure 42. The considered approach uses a fix safety buffer and individual fill rates for all articles in a specific article class.

Approach 2: Individual safety times and fix fill rates.

The second approach also uses the fill rates from the modified ABC-matrix. This approach is however using the fill rate to through simulations determine the corresponding safety time for each article. As for approach 1, to avoid interference with the kitting activities of some *forecast based articles* prior to production and at the same time avoid unreasonably long safety times, minimum and maximum safety times are set to 2 and 20 days. The obtained safety times have all been rounded up to the closest integer, which leads to a slightly higher obtained average fill rate than initially set. As with the first presented approach, the change in capital employed in *safety buffers* compared to the best *safety buffer* with the ABC method is presented, see table 12.

Table 12. The results in terms of employed capital, safety times and obtained average fill rates. The results are compared to UCMSWE's currently used ABC method.

Approach 2: Individual safety times and fix fill rates		
Article class	**Safety time**	**Obtained average fill rate**
Class A	2-20 Days	96,5%
Class B	2-20 Days	98,5%
Class C	2-20 Days	99,4%
Total change in capital employed in safety buffer:		**+16%**

Table 12 shows that the employed capital is higher for this approach compared to UCMSWE's best *safety buffer* with the ABC method and the first introduced approach. At the same time, all approaches generate comparable average fill rates. On the other hand, it is important to remember that by using an article specific safety time, the fill rate for each article is much closer the desirable fill rate. The only deviation is a result of the requested minimum and maximum safety times and round-ups of calculated safety times. This means that the lowest fill rate with approach 2 is much higher than the lowest fill rate with approach 1. Approach 2 also gives a reduced spread in the upper part of the interval where the highest fill rate is lower than with approach 1. An example of the structure of how the articles in one class receive their individual safety times is expressed with the trade-off between *safety buffer* and fill rate in figure 43.

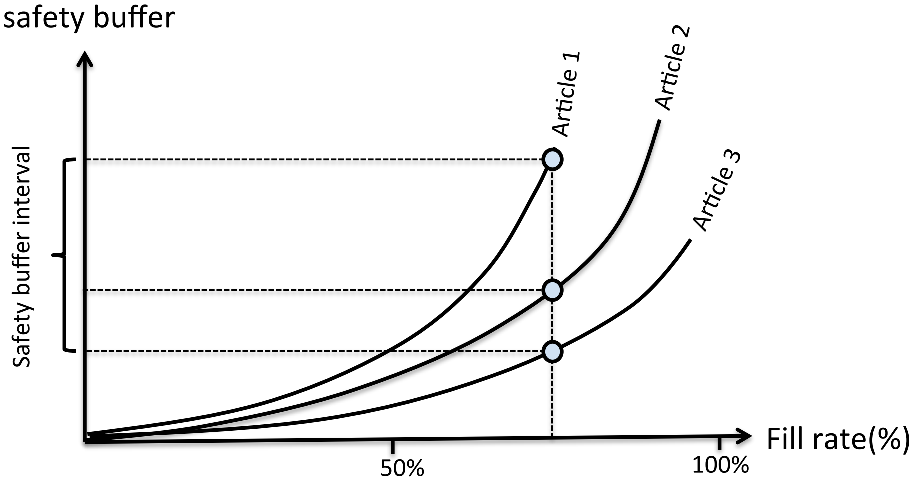

Figure 43. The considered approach uses varying safety buffers and a fix fill rate for all articles in a specific article class.

5.2.3 Results – Safety buffers

The standpoint in the evaluation of how much the employed capital can be reduced by changing approach for *safety buffer* determination is once again based on the difference between the best *safety buffer* with the ABC method and the two proposed approaches, see table 13.

Table 13. The results of the capital employed and obtained average fill rates from the best safety buffer with ABC method, the approach 1 and approach 2.

	Best safety buffer with ABC method	Approach 1	Approach 2
Capital employed in safety buffer	100%	-26%	+16%
Obtained average fill rate	A: 95,6% B: 97,9% C: 100%	A: 96,2% B: 98,0% C: 99,2%	A: 96,5% B: 98,5% C: 99,4%
Spread of fill-rate	Intermediate	Highest	Lowest

The first approach would generate a 26 percent reduction of the capital employed in *safety buffer* and therefore has the best short-term effect on the inventory turnover rate. By solely decreasing the *safety buffer* with the first approach, the total capital employed in inventory would decrease by 5 percent, which would increase the inventory turnover rate from 11,6 to 12,2 annual turns, see equation 41.

$$Inventory\ turnover\ rate = \frac{11{,}6\ (current)}{100\% - 5\%} = 12{,}2\ (41)$$

The second approach would instead increase the total capital with 3 percent, which would lead to a decrease of the inventory turnover rate from 11,6 to 11,2 annual turns, see equation 42.

$$Inventory\ turnover\ rate = \frac{11{,}6\ (current)}{100\% + 3\%} = 11{,}2\ (42)$$

The obtained average fill rates all satisfy the goals of reaching 95 percent for class A, 97 percent for class B and 99 percent for class C. Anyhow, as previous explained, the spread of fill rates in each class depend on the approach used. In general, the spread will be larger if more articles are handled in the same way as is done in the best *safety buffer* with the ABC method and approach 1. Approach 2 gives each article a target fill rate, except for the ones that would have fallen outside the bottom or top limits of 2 and 20 days. Even though the second approach ties up more capital, this approach is likely to result in less inventory deficits and therefore save the company money in terms of fewer production stops. The cost of production stops has not been analysed and it is thus difficult to quantify the improvement potential.

5.3 Part 3: Complementary factors

By analysing the inventory levels for the *forecast based articles* during 2013, it has been understood that more factors than order quantities and explicitly defined *safety buffers* have considerable influence on UCMSWE's inventory levels. The real *safety buffer* with the ABC method has been calculated using 2013's transaction data and is compared to the best *safety buffer* with the ABC method. The analysis shows that the real *safety buffer* with the ABC method results in a *safety buffer* that is 3,4 times bigger than the best *safety buffer* with the ABC method's *safety buffers*, see table 14. The table also shows the minimum fill rate of the best and real *safety buffer* with the ABC method: 35 and 79 percent. The reason why the real *safety buffer* with the ABC method has a higher minimum fill rate is due to complementary factors.

Table 14. The difference between best and real safety buffer with the ABC method.

	Best safety buffer with ABC method	**Real safety buffer with ABC method**
Capital employed in safety buffer	-	+340%
Obtained average fill rate	A: 95,6% B: 97,9% C: 100%	A: 99,5% B: 99,7% C: 99,8%
Minimum fill rate	35%	79%

It has not been the aim of the research to fully understand all complementary factors influencing the inventory levels at UCMSWE. However, due to some complementary factors' considerable influence on the inventory levels, they have been analysed as thoroughly as possible with the existing theoretical framework and empirical findings. This has resulted in a more qualitative analysis except for the first part about delivery windows, which was analysed quantitatively.

5.3.1 Delivery windows

It has been possible to quantify the improvement potential concerning the number of delivery windows. Transaction data for a sample of three articles allocated in article class A with one delivery window per week has been simulated to have an additional time slot for deliveries each week. The total number of deliveries is however remained due to the constant number of article transported each time. The analysed area is instead the effect of a more flexible delivery schedule. By comparing the best practice of scheduling deliveries with one and two delivery windows per week, simulations showed that a second weekly delivery window results in a reduction of 5 to 7 percent of the average inventory levels.

The test period covers all inventory transactions from September to December 2013 and for the class A1 article described in figure 44, three out of seven deliveries during the test period would have been re-scheduled if an additional delivery window had been introduced, resulting in a 7 percent reduction of the average inventory level.

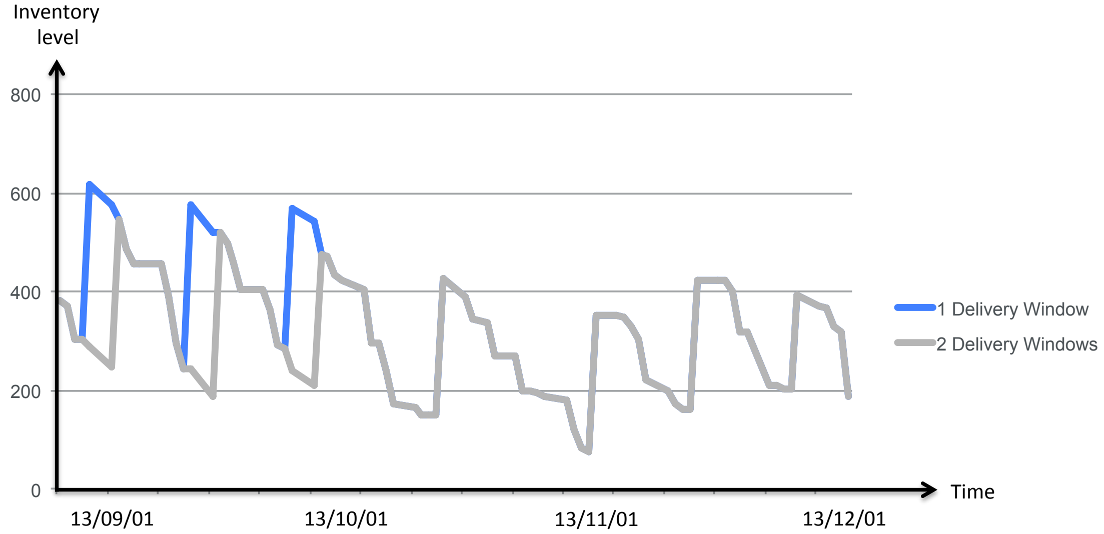

Figure 44. The inventory level during 3 months for a class A1 article described in two cases: with one and with two delivery windows per week.

The potential for inventory turnover rate improvements from introduction of additional delivery days is estimated to be considerable. To introduce a second weekly delivery window for some of the 150 suppliers with only a single weekly time slot today would most likely result in a higher inventory turnover rate. Focus should primarily be towards suppliers with the largest volume values since they potentially generate larger inventory reduction. Anyhow, the estimated improvement potential only compares the theoretical best practice where all order proposals generated by the *MPC-system* are accepted without adjustments.

5.3.2 Qualitative analysis of complementary factors

When looking at plots of articles' inventory levels during 2013, it is possible to visualise the inventory generated by some complementary factors. Even though it has been shown that the total employed capital in *safety buffers* is 3,4 times higher than best *safety buffer* with the ABC method, it does not mean that all articles show the same pattern. To be able to express the identified problems, two example articles have been selected. One is the article with the highest volume value of all UCMSWE's *forecast based articles* and the second article is selected because it appears early in the manufacturing process, which has been found to be more sensitive for errors in terms of production planning.

The top article in terms of volume value is a complete drive unit and is classified as an A1 article. When plotting the graph of this article's inventory level, it is possible to see a fluctuating behaviour in transactions in and out from the inventory, see figure 45.

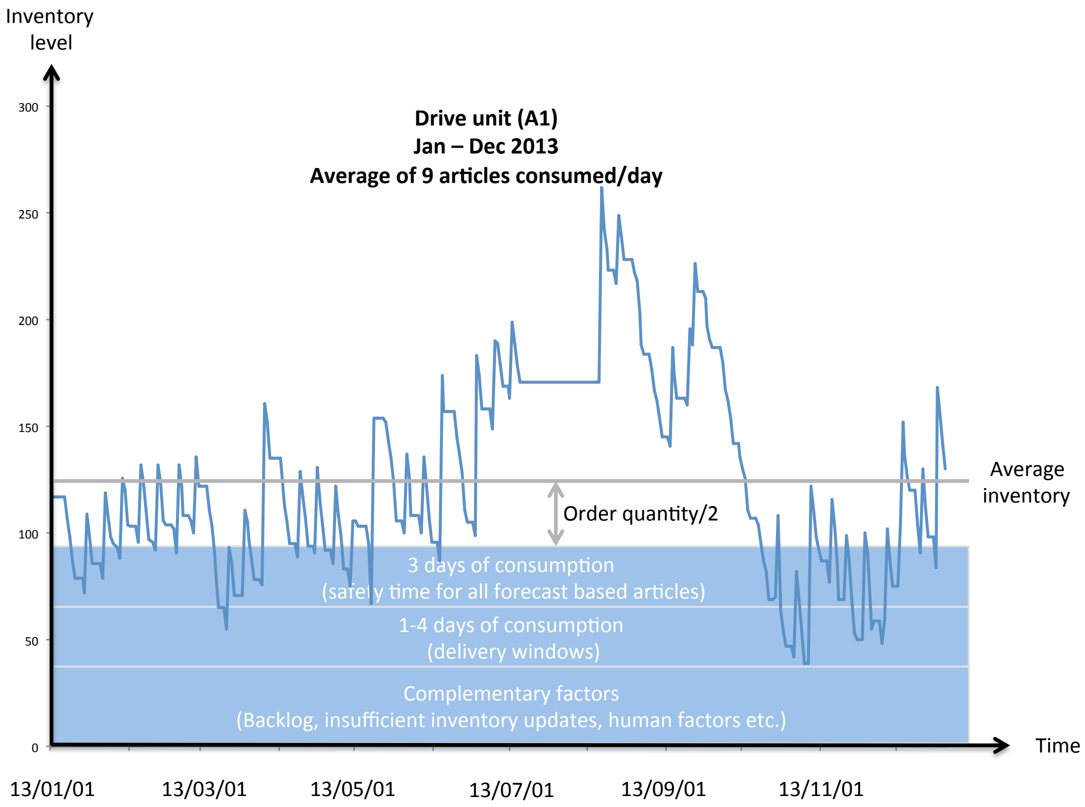

Figure 45. An inventory level plot for the article with the highest volume value at UCMSWE.

The safety stock has been calculated based on 2013's transaction data. The calculation resulted in a safety stock of 98 articles, equation 43.

$$Safety\ stock = Average\ inventory - \frac{Order\ quantity}{2} = 122 - \frac{48}{2} = 98 \quad (43)$$

Since the average daily consumption is 9 articles, the current use of three days of safety time equals a safety stock of 27 articles, which is less than the 98 articles calculated above. As seen in figure 45, only 27 articles in safety stock would be insufficient and lead to inventory deficits during almost half of the year. Even with the maximum mismatch between delivery window and consumption date (another four days in inventory), the safety stock would still only equal 63 articles. Therefore other factors influencing the inventory level must be present to add up to 98 articles in safety stock for this article. It is easy to see that the inventory is built up prior to holidays, which increases the average inventory and therefore also the safety stock calculated. Still orders seem to be placed at occasions where there are no needs for placing orders.

Moving on to the second selected article, which is the same article as in figure 27 chapter 4.2.6 and the graph is as previously marked with ticks to show the influence of order quantities. The current three days of safety time, which corresponds to 9 articles, is also added as the top part of the safety stock. The effect of delivery windows' influence is market out underneath the three days of safety time, see figure 46.

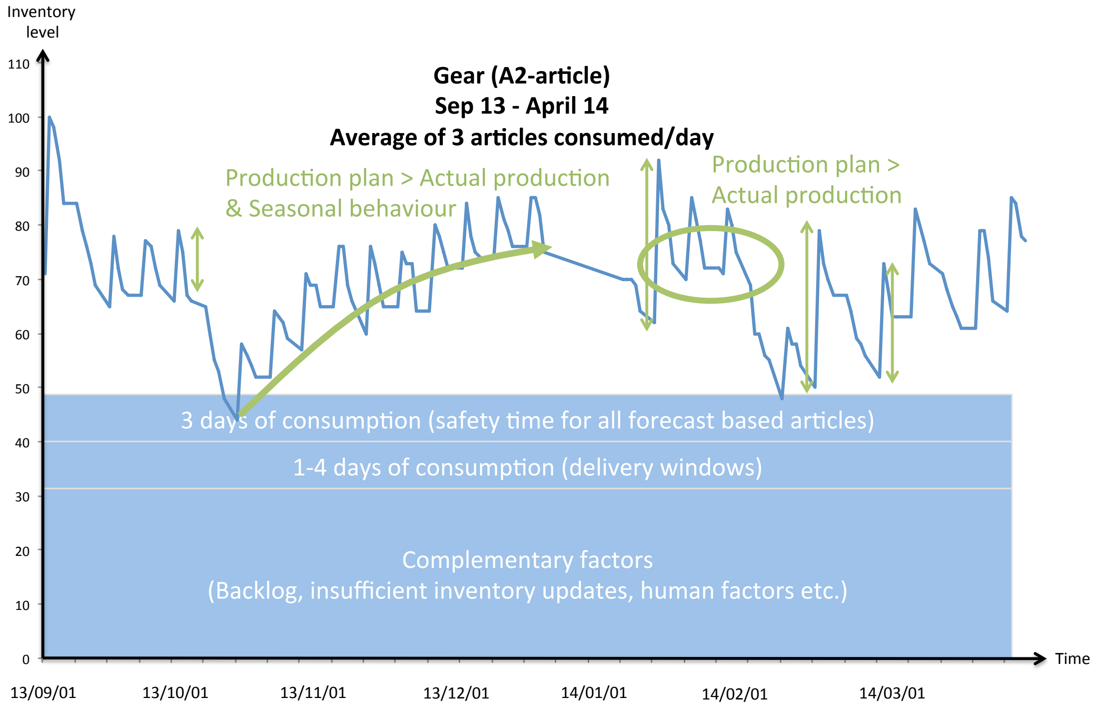

Figure 46. The discovered rational behind the inventory level curve for an example article.

In contrast to the top volume value article, the three days of safety time would be sufficient during the examined period. It is only possible to speculate where and to what extent the complementary factors influence, because of the lack of quantitative information to support an analysis. The material planning method is believed to have considerable influence on the inventory, especially for articles with long lead-times and that are early in the production process. These articles are if the order stock is short forecast driven in the ordering process. If the forecast is higher than the actual production, orders arrive even though the inventory levels are high. This is exemplified with the circle and arrow in the figure.

Multiples of order quantities

By looking at the two example articles' graphs it is possible to notice that the inbound transactions are not equal in size each time. This is due to periods of high demand where more than one order quantity needs to be ordered to cover the demand. Even during periods with high demand, a double order quantity most often exceeds the need. It would lead to extra work if each order placement decision had to be manually adjusted. An approach to solve this is already tested by UCMSWE and is believed to be the most realistic solution in this area. The tested approach is that the order quantity calculated should be fix and used as long as the demand does not exceed the order quantity, but if it does a multiple of a smaller quantity is added to meet the demand. This quantity could for example be whole pallets, entire plates or beams of raw material or an extra trailer. The smaller the extra quantity is the less unnecessary inventory would be held.

Stock quantity errors

The box with complementary factors shown in figure 46 could to some extent be explained by incorrect updates of information about UCMSWE's internal material flow. This could have the effect that the inventory levels are either higher or lower in the *MPC-system* than the actual inventory level are, as described in chapter 4.3.2. This is a problem when stock counting is performed, since the employees cannot be sure whether the article level in the actual inventory is correct or if some articles in production should be counted because they have not been reported as consumed. This has probably not considerable effects but creates fluctuation errors in the *MPC-system's* inventory levels.

Human factors

The human factor is difficult to specify but is a widespread problem in many companies. The most important analysis is to understand where information may be misinterpreted and where decision support is insufficient. Observed areas where the human factor may influence the inventory levels at UCMSWE is when the ABC-matrix is used to specify entered supplier agreements and when the focus is on *purchasing price* and not *purchasing cost*. These findings must be communicated to all involved and transformed into guidelines.

6 CONCLUSION AND DISCUSSION

This chapter answers to the purpose as well as giving explicit recommendations to UCMSWE. The first research question about how UCMSWE manages its procurement of forecast based articles has been answered through the empirical findings. The analysis has pointed out imperfections in how UCMSWE uses inventory policy measures in its procurement process, which answers to the second research question. How lot sizing and safety buffers can be used to increase the inventory turnover rate has also been answered in the analysis, corresponding to the third and last research question. Key findings from all three parts of the analysis are presented in this chapter, followed by recommendations to UCMSWE.

Conclusion & Discussion Part 1: Lot sizing method

A new lot sizing method that considers the *forecast based articles'* unique characteristics is proposed to UCMSWE. The proposed method determines order quantities with EOQ-calculations considering the inventory-carrying factor, the ordering cost, the consumption and the price as input parameters. Simulations indicate a 7,5 percent reduction of employed capital in inbound inventory between the best *safety buffer* with the current ABC method and the best *safety buffer* with the proposed EOQ method. The drop in employed capital would push the inventory turnover rate from 11,6 to 12,5 annual turns. The input parameters have to be updates regularly to maintain the EOQ method's advantage. It has therefore been important to be transparent about the calculations and related assumptions.

Conclusion & Discussion Part 2: Safety buffer method

The analysis suggests two possible approaches to replace the existing safety buffers at UCMSWE. Both approaches use the modified ABC-matrix with three article classes, corresponding to the current ABC-matrix's volume value classes A, B and C. Compared to the explicitly expressed *safety buffers* today, approach 1 would decrease the employed capital in the inbound inventory with 6 percent and thus increase the inventory turnover rate. Approach 2 would lower the inventory turnover rate because of an employed capital increase of 3 percent, while decreasing the spread of fill rates in each article class.

Approach 2 is believed to be the better alternative since it constitutes a more sustainable way to work. The result from the analysis of 2013's transaction data indicates that the actual fill rates and capital employed is far higher than the theoretical ones. This strengthens the recommendation of the second approach, since it enables UCMSWE to eliminate other inventory building factors and simultaneously keep sufficient fill rates.

Conclusion & Discussion Part 3: Complementary factors

Some interesting factors have been discovered that first were believed to be outside the scope of this research but later found to have strong relationships to the inventory levels and hence important to understand. Therefore some conclusions and discussion have been drawn from this area.

The delivery windows influence the inventory levels and by increasing the number of delivery windows from once to twice a week, simulations indicate that the inventory levels could be reduced with 5 to 7 percent. Because of the limited time spent to analyse this area, it is recommended to perform extended simulations before implementing major changes. It is recommended to start a pilot project for the suppliers with the largest volume values if the results of the extended simulations are promising.

It is proposed to introduce other multiples to enable smoother order quantity adjustments and thereby generate order quantities closer to the actual demand. Multiples should be built on the smallest unit load for an article, e.g. a pallet or other shipping quantities and could be successful but need further research.

Updating of inventory levels into the *MPC-system* and the way the system order according to forecast is also an area recommended for future research. An identified problem is long lead-times in combination with short order stock. Another problem is when the production plan does not correspond to the actual production. These problems have to be further investigated.

Recommendations to the company
The recommendations are given in a bullet list to facilitate the overview and to easier tick already taken actions.

- Calculate EOQ
    - Distribute the transportation costs according to the proposed modified standard price factor
    - Use the calculated inventory-carrying factor
    - Use the calculated ordering cost

- Redefine ABC-matrix for safety buffer determination
    - Use solely volume value as inventory policy measure
    - Use only three article classes with fill rate as control parameter
    - Give each article an individual safety time

- Introduce more delivery windows
    - Start by introducing a pilot project

- Use the excel-tool to generate order quantities and safety times regularly
    - To introduce new suppliers and articles
    - To update current ones

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APPENDIX 1 – Interview List

2014-02-05: **Johan Rydén (Logistics manager)**
An interview with focus on UCMSWE's ABC-matrix, its inventory policy measures and control parameters.

2014-02-06: **Sören Fransson (Business controller)**
An interview with focus on pricing of articles and the difference between purchasing price and standard price.

2014-02-12: **Erik Palmqvist (Internal logistics)**
An interview with focus on internal logistics.

2014-02-12: **Nathalie (Material planner)**
An interview with focus on the order placement procedure for forecast based articles.

2014-02-12: **Jan Lindblad (Business controller)**
An interview with focus of employed capital in UNCSWE's inbound inventory, the magnitude and how it is calculated.

2014-02-19: **Lovisa Andersdotter (Strategic buyer)**
An interview with focus on the differences between theoretical order quantities and MPC-system order quantities.

2014-03-03: **Stig-Arne Mattsson (Researcher within inventory management)**
An interview regarding inventory management.

2014-03-31: **Erik Palmqivst (Internal logistics)**
An interview with focus on the organisational structure of UCMSWE's purchasing and logistics division.

2014-03-31: **Frank Paulsen (Main planning manager)**
An interview with focus on how the MPC-system works with real and forecasted demand.

APPENDIX 2 – Cost Components To Determine The Inventory-Carrying Factor

Capital costs	Costs for depreciation
Costs for premises	Scrapping costs
Costs for shelves, racks, etc.	Wastage costs
Handling equipment costs	Costs for physical inventory
Handling costs	Administrative costs
Insurance costs	Data processing costs

APPENDIX 3 – Costs To Consider When Determining Ordering Costs

Request for quotation	Goods reception
Supplier negotiation	Inspection
Selection of supplier	Put away in stock
Purchase order/order proposal	Delivery reporting
Purchase order processing	Internal transportation
Delivery monitoring	Invoice check
Other supplier contracts	Payment
External transportation	

APPENDIX 4 – Normal Distribution Table

Normal distribution table

Safety factor	Service level %	Safety factor	Service level %	Safety factor	Service level %	Safety factor	Service level %
0,00	50,0	0,72	76,4	1,44	92,5	2,16	98,5
0,02	50,8	0,74	77,0	1,46	92,8	2,18	98,5
0,04	51,6	0,76	77,6	1,48	93,1	2,20	98,6
0,06	52,4	0,78	78,2	1,50	93,3	2,22	98,7
0,08	53,2	0,80	78,8	1,52	93,6	2,24	98,7
0,10	54,0	0,82	79,4	1,54	93,8	2,26	98,8
0,12	54,8	0,84	80,0	1,56	94,1	2,28	98,9
0,14	55,6	0,86	80,5	1,58	94,3	2,30	98,9
0,16	56,4	0,88	81,1	1,60	94,5	2,32	99,0
0,18	57,1	0,90	81,6	1,62	94,7	2,34	99,0
0,20	57,9	0,92	82,1	1,64	94,9	2,36	99,1
0,22	58,7	0,94	82,6	1,66	95,2	2,38	99,1
0,24	59,5	0,96	83,1	1,68	95,4	2,40	99,2
0,26	60,3	0,98	83,6	1,70	95,5	2,42	99,2
0,28	61,0	1,00	84,1	1,72	95,7	2,44	99,3
0,30	61,8	1,02	84,6	1,74	95,9	2,46	99,3
0,32	62,6	1,04	85,1	1,76	96,1	2,48	99,3
0,34	63,3	1,06	85,5	1,78	96,2	2,50	99,4
0,36	64,1	1,08	86,0	1,80	96,4	2,52	99,4
0,38	64,8	1,10	86,4	1,82	96,6	2,54	99,4
0,40	65,5	1,12	86,9	1,84	96,7	2,56	99,5
0,42	66,3	1,14	87,3	1,86	96,9	2,58	99,5
0,44	67,0	1,16	87,7	1,88	97,0	2,60	99,5
0,46	67,7	1,18	88,1	1,90	97,1	2,62	99,6
0,48	68,4	1,20	88,5	1,92	97,3	2,64	99,6
0,50	69,1	1,22	88,9	1,94	97,4	2,66	99,6
0,52	69,8	1,24	89,3	1,96	97,5	2,68	99,6
0,54	70,5	1,26	89,6	1,98	97,6	2,70	99,7
0,56	71,2	1,28	90,0	2,00	97,7	2,72	99,7
0,58	71,9	1,30	90,3	2,02	97,8	2,74	99,7
0,60	72,6	1,32	90,7	2,04	97,9	2,76	99,7
0,62	73,2	1,34	91,0	2,06	98,0	2,78	99,7
0,64	73,9	1,36	91,3	2,08	98,1	2,80	99,7
0,66	74,5	1,38	91,6	2,10	98,2	2,82	99,8
0,68	75,2	1,40	91,9	2,12	98,3	2,84	99,8
0,70	75,8	1,42	92,2	2,14	98,4	2,86	99,8

APPENDIX 5 – Service Loss Function Table

Service loss function E(z)

Safety factor	Service function	Safety factor	Service function	Safety factor	Service function	Safety factor	Service function
0,00	0,3989	0,72	0,1381	1,44	0,0336	2,16	0,0055
0,02	0,3890	0,74	0,1334	1,46	0,0321	2,18	0,0052
0,04	0,3793	0,76	0,1289	1,48	0,0307	2,20	0,0049
0,06	0,3697	0,78	0,1245	1,50	0,0293	2,22	0,0046
0,08	0,3602	0,80	0,1202	1,52	0,0280	2,24	0,0044
0,10	0,3509	0,82	0,1160	1,54	0,0267	2,26	0,0041
0,12	0,3418	0,84	0,1120	1,56	0,0255	2,28	0,0039
0,14	0,3328	0,86	0,1080	1,58	0,0244	2,30	0,0037
0,16	0,3240	0,88	0,1042	1,60	0,0232	2,32	0,0035
0,18	0,3154	0,90	0,1004	1,62	0,0222	2,34	0,0033
0,20	0,3069	0,92	0,0968	1,64	0,0211	2,36	0,0031
0,22	0,2986	0,94	0,0933	1,66	0,0201	2,38	0,0029
0,24	0,2904	0,96	0,0899	1,68	0,0192	2,40	0,0027
0,26	0,2824	0,98	0,0865	1,70	0,0183	2,42	0,0026
0,28	0,2745	1,00	0,0833	1,72	0,0174	2,44	0,0024
0,30	0,2668	1,02	0,0802	1,74	0,0166	2,46	0,0023
0,32	0,2592	1,04	0,0772	1,76	0,0158	2,48	0,0021
0,34	0,2518	1,06	0,0742	1,78	0,0150	2,50	0,0020
0,36	0,2445	1,08	0,0714	1,80	0,0143	2,52	0,0019
0,38	0,2374	1,10	0,0686	1,82	0,0136	2,54	0,0018
0,40	0,2304	1,12	0,0659	1,84	0,0129	2,56	0,0017
0,42	0,2236	1,14	0,0634	1,86	0,0123	2,58	0,0016
0,44	0,2169	1,16	0,0609	1,88	0,0116	2,60	0,0015
0,46	0,2104	1,18	0,0584	1,90	0,0111	2,62	0,0014
0,48	0,2040	1,20	0,0561	1,92	0,0105	2,64	0,0013
0,50	0,1978	1,22	0,0538	1,94	0,0100	2,66	0,0012
0,52	0,1917	1,24	0,0517	1,96	0,0094	2,68	0,0011
0,54	0,1857	1,26	0,0495	1,98	0,0090	2,70	0,0011
0,56	0,1799	1,28	0,0475	2,00	0,0085	2,72	0,0010
0,58	0,1742	1,30	0,0455	2,02	0,0080	2,74	0,0009
0,60	0,1687	1,32	0,0436	2,04	0,0076	2,76	0,0009
0,62	0,1633	1,34	0,0418	2,06	0,0072	2,78	0,0008
0,64	0,1580	1,36	0,0400	2,08	0,0068	2,80	0,0008
0,66	0,1528	1,38	0,0383	2,10	0,0065	2,82	0,0007
0,68	0,1478	1,40	0,0367	2,12	0,0061	2,84	0,0007
0,70	0,1429	1,42	0,0351	2,14	0,0058	2,86	0,0006

APPENDIX 6 – A Derivation Of Fix Safety Stock Into Days Of Safety Time

$$Fix\ safety\ stock = 8\% \times Annual\ consumption$$

$$Average\ daily\ consumption = \frac{Annual\ consumption}{220\ days\ of\ production}$$

$$Fix\ safety\ stock\ in\ days = \frac{Fix\ safety\ stock}{Average\ daily\ consumption} =$$

$$= \frac{8\% \times Annual\ consumption}{\frac{Annual\ consumption}{220\ days\ of\ production}} = 8\% \times 220\ days\ of\ production = 17{,}6\ days$$