An improvement of the logistic performance for a supplier in a single echelon supply chain by implementing sales lead times in the safety stock policy.

A case study at Bosch Rexroth AB

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Sammanfattning


Bosch Rexroth har nyligen infört säljledtider gentemot kund, detta skapar utrymme för att minska lagret. Samtidigt kan deras produkter säljas på två sätt, som reservdel eller så kan den användas som komponent i deras produktion. För dessa tre ändamål har produkten en bestämd inköpsledtid, men tre olika säljledtider och säljs i olika kvantiteter för de tre olika ändamålen. Med dessa förutsättningar har vi undersökt vilka möjligheter som finns till att förbättra den logistiska prestandan då ett väl koordinerat säkerhetslager kan leda till kostnadsbesparingar på mer än 15 % (Kelle, 2005).

I detta arbete har två olika koncepts utvärderats, en ny säkerhetslagerberäkning och en alternativ ABC-klassificering. Dessa två koncept utvärderades genom simulering i ExtendSim för att se att de nådde upp till samma fyllnadsgrad som tidigare. Våra resultat visar att det med en alternativ ABC-klassificering och en förfinad säkerhetslagerberäkning går att sänka säkerhetslagerkostnaderna med nästan 60 % utan att minska fyllnadsgraden. Fyllnadsgraden mättes genom ett flertal simuleringar med data insamlad både ifrån fallstudien och slumpmässig.
Abstract

Logistics management is increasingly seen as a source for competitive advantage. Managing it efficiently leads to reduced costs which provide the company the opportunity to increase their market shares (Christopher, 1998). The usage of warehouses is an important aspect in logistic management. Warehouses are however usually associated with increased costs rather than increased customer value. Companies therefore strive to reduce all costs associated with warehousing by minimizing the time items are stored in the warehouse (Crocker, et al., 2012). By lowering the inventory, the companies however increase their risk for stock-outs which may lead to increased cost rather than decreased along with annulled orders. To prevent such things from happening companies can apply a safety inventory. The safety inventory also known as the safety stock is intended to handle such risk that is caused by variations. These variations are usually associated with fluctuations in demand, delayed replenishment orders or deviation in quantity. If the safety stock is coordinated well it can lead to cost savings of more than 15 % (Kelle, 2005).

Bosch Rexroth AB have recently implemented a sales lead time in their business strategy with aim to reduce the inventory costs hence make them more competitive. However, even after these changes the safety stock policy has remained the same. In this report alternative calculation methods have been investigated with expectation to decrease the safety inventory costs while keeping the same level of. Furthermore, the current ABC-classification has been investigated as well.

In this work two different concepts were reviewed, a new safety stock calculation and a new ABC-classification, with aim to integrate the sales lead times. In the end, a combination of these concepts where used which resulted in a reduction of the safety inventory by 60 % while remaining the same level of delivery performance. The delivery performance was measured through multiply simulations with both real data gathered from the case study and randomized numbers.
Preface

This master thesis was written during the spring 2016 as the final part in our education at the Industrial Engineering and Management at the Royal Institute of Technology. The case study was carried out at Bosch Rexroth AB (previous Bosch Rexroth Mellansel AB) located in Mellansel Sweden during a two months’ period. The interviews where done with Bosch Rexroth employees working at the inventory department and a smaller exchange of emails where done with Alexander Wücht, supply chain manager of Bosch Rexroth’s headquarter in Lohr, Germany. Furthermore, the simulations where made in the commercialized simulation software ExtendSim9, created by Imagine That Inc.

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1 Introduction

The initial chapter aims to provide the reader with a brief description of the problem and background behind its existence. Furthermore, it strives to explain the purpose of the paper, its limitations and the methodology of choice.

1.1 Background

Logistics management is increasingly seen as a source for competitive advantage. Managing it efficiently leads to reduced costs which provide the company the opportunity to increase their market shares (Christopher, 1998). The usage of warehouses is an important aspect in logistic management. A warehouse can have four different purposes, breaking bulk, creating bulk, smoothing or combining goods. Warehouses are however usually associated with increased costs rather than increased customer value. Companies therefore strive to reduce all costs associated with warehousing by minimizing the time items are stored in the warehouse. (Crocker, et al., 2012)

Bosch Rexroth is a supplier of hydraulic motors and driving units for several different customers worldwide. Their products can be used in a wide range of applications, e.g. sugar crosses, milling and oil drilling. Bosch Rexroth is assembling and delivering products to their sales offices and the final customer, in locations worldwide. Bosch Rexroth primary source of income is the sales of hydraulic motors and driving units. To be competitive and have an additional source of income they are also offering services for their hydraulic motors and driving units. One part of this service is to offer spare parts. As their equipment has a long life time they need to have spare parts for several generations of motors. This leads to an inventory consisting of several thousands of products. Every customer wants to have their order delivered immediately, to be able to do so Bosch Rexroth needs to have all these products kept in stock. However, this is not cost effective wherefore some products are higher prioritized than others. A customer order can consist of a single part or several products of more complex sort. Some products can be delivered immediately whilst others need to be assembled before delivery. To be transparent towards their customers Bosch Rexroth have introduced sales lead times. In general, if a product is important for the market it will have short sales lead time and vice versa, although there are exceptions. With the introduced sales lead times the company can deliver their products later and could therefore reduce their stock levels.

Lowering the inventory however leads to increased risk of stock outs due to the uncertainty in demand. The costs associated with stock outs are usually higher than initially expected. Other than a delayed delivery, a stock out may also lead to annulled orders and furthermore reduced goodwill. To reduce the risk of running out of supplies or products in a warehouse, companies can use a so called safety inventory. Using a safety inventory is especially useful when working with long lead times, large variance in either supply or demand or when the alternative costs, as mentioned earlier (annulled orders and reduced goodwill), exceeds the cost of keeping inventory. To satisfy a safety stock policy, the reorder point should be set so that it remains a few products in the storage even at the time of delivery, the amount left corresponds to the safety stock level. (Sunil & Meindl, 2007)

In reality, companies often work with hundreds or thousands of different items which complicates the inventory management remarkable. To handle this dilemma, enterprises use software to systematically store and share the data within the company, making it available when deciding or updating the inventory policy. Such software is known as enterprise resource planning system.

Enterprise resource planning (ERP)-systems are a software used by many of today’s companies to handle the data and make it available and visible for the companies’ employees. One area of usage is
to more efficiently navigate the supply chain or reduce inventories by creating a model representing customer demand (Umble, et al., 2003). In the ERP-systems a safety stock level can be calculated based on the historical demand, historical lead times and the desired service level. The service level is normally based on the ABC-classification. The ABC-classification is an analysis used to categorize items based on their demand and sales value to later evaluate which of the items that have a significant impact on the total inventory cost (Vollmann, 2011). Those different categories of items will in return need different management and serviceability due to their difference in volume. An item classified as A should have a higher degree of management and be reviewed constantly. Whilst the remaining groups can be less reviewed and in particular the C-classification can be ordered in higher volumes and be stored for a longer period (Teunter, et al., 2010). Coordinating the safety stock well can lead to cost savings of more than 15% (Kelle, 2005).

However, even with an efficient usage of the ERP-system, the inventory management still faces the dilemma of deciding the appropriate level of responsiveness. The easiest and most common way to increase the responsiveness is to adjust the safety stock levels. By increasing the safety stock levels companies can offer a higher responsiveness but at an increased cost. Bosch Rexroth AB are facing this dilemma in their enterprise.

In general Bosch Rexroth has too high inventory levels causing high capital binding and costs. In particular, the problem is the connection between the inventory policy and the offered sales lead times as expressed by the logistics manager at Bosch Rexroth. The sales lead time is a promise made by Bosch Rexroth to their customers that their order will be shipped from their warehouse within these days. The set time is mostly based on market input and has no connection to replenishment lead time or the classification of the product. The goal of implementing the sales lead time was to eventually reduce the inventory costs. However, the current safety stock levels have not been adjusted to the recent change leading to a gap between the offered sales lead times and the inventory level. The consequence is inadequate stock levels which furthermore may lead to stock outs and non-satisfied lead times and a non-cost efficient inventory system. The ERP-system can calculate a safety stock based on replenishment lead times, but can currently not take into account the sales lead times. Furthermore, an item can be sold as a spare part, part of kit or used in production. For a kit the item will get a new item number and have its own stock. But for the other purposes one item will have the same stock but different sales lead times and different demand patterns which have to be taken into account considering the safety stock policy. The inventory consists of thousands of items, with very different usage, some of the items have forecasts while others do not. Although the safety stock is used in the same way, which means that there might be an additional reason to the undefined inventory.

An increased safety stock will cause higher inventory costs and more administration. While an insufficient level of safety stock will increase the risk for stock outs. This will consequently lead to additional costs in terms of delayed deliveries, annulled orders or production stop. Furthermore, the variance in product offer as described earlier increases the problematization. In particularly it is problematic that some products are sold as single as spare parts, or used as components in production with different demand patterns.

Since the described problem mostly occurs on a functional level in the organizations with the problem coming up in the production planning process. The inaccuracy of the planning causing poorly made calculations within the ERP-system. The problem can also however be seen on an industrial level, with the implementation of sales lead times and its poor connected to the inventory management. Globalized markets with higher competitiveness and the residual customer demand regarding quick delivery (Milgrom & Roberts, 1990) which causes the variations in sales lead times.
The problem can though be seen as a necessity to further reduce sales lead times and replenishment lead times. Although, herein we will mainly focus on the functional level, how to improve the calculations in the production planning process. In order to do so the communication gap on the functional level needs to be solved.

1.2 The goal of this study

Earlier years, Bosch Rexroth has had a sufficient level of sales, while achieving a good profit with continues focus on keeping the volumes high. On later years the market has changed with a decrease in market demand. This has consequently decreased the sales volumes and forced Bosch Rexroth to change their focus. Their current focus is to increase the margins. One way of doing so is to reduce the inventory costs. Since Bosch Rexroth product portfolio contains both items sold as spare parts and manufactured products thy can be seen as both a logistical warehouse and a manufacturer. The problem occurs for spare parts which are delivered immediately to the customer and for items used in production. For instance, an item that has in the past been offered with a month sales lead time, has more than a month replenishment time and no safety stock, can at any time be changed to have a sales lead time of one week, if that is the general requirement of the market. These types of products would therefore require an increased safety stock level to reduce the risk of delayed deliveries. These would also apply the other way around, products with increased delivery time could have a reduced safety stock level to reduce inventory costs. The problem also occurs for items used in production, there it is important to have a high availability of raw material to not have a stop in the production.

The goal of this project is to further analyze the current state at Bosch Rexroth and find a feasible inventory policy that will outperform the current inventory situation. The most used KPI at Bosch Rexroth is the average stock value. Their business goal is to decrease the value and one way of doing so is to decrease the safety stock levels. Although the decreased stock value, should have none or minimum affect the current warehouse performance and in particular the product fill rate. Today they are only measuring the delivery performance, at which they have a general sufficient level. The delivery performance should also not be decreased. As the market recognizes shorter sales lead times, the model should be dynamic.

The purpose of this master thesis is to evaluate the possibility of enhancing the current safety stock calculations without having a negative impact on the warehouse performance by integrating the sales lead times and looking at the possibility of an extension of the current ABC-classification, in order to reduce overall inventory costs. To enhance the ABC-classification we will firstly evaluate the condition of the existing classification to make sure it's working as intended before considering alternative methods.

When looking at the problem and the study object the following research question will be answered:

*How can a multi-product supplier minimize their safety stock levels by integrating their sales lead times in the calculations without compromising on the overall warehouse performance?*

In order to answer the main research question, these sub-questions will be included.

1. *How can sales lead times be integrated in the calculation of the safety stock levels?*
2. *Can the service level matrix be developed to better adapt to the current situation?*
3. *Are there any other parameters that should be taken into account in the safety stock calculations?*
1.3 Limitation

The master thesis has been limited to focus on making the calculation in a so called excel bolt-on (Farasyn, et al., 2008) and not changing the calculations within the ERP-system. The bolt-on should be generally constructed to be compatible with exported data from both ERP-systems. To decrease the average stock value, there are more variables to change to reduce the levels which will not be subject to research in this work, such as replenishment lead times, order quantity and production batches. All those will be treated as fixed variables herein. Furthermore, as the replenishment cost is different between items and customers, it will not be included in this research and the goal will not be to decrease these costs. Instead our goal is to maintain the same average fill rate while decreasing the average stock value which will in turn result in reduced tied up capital and costs. Since the goal is to achieve the same product fill rate, rather than the order fill rate, no consideration will be made about correlation between products. The model is intended to dimension the raw material stock and will thus not consider sub-assembly storages.

1.4 Outline of the project

Initially a Gantt chart with milestones was created in order to have brief view of the outcome of the project. Along the way the project changed a bit, although the Gantt chart was used to see how the project were performing according to the initial time plan to be sure to make it on time. The project was executed in three phases.

1:st Phase
- Preliminary Interviews
- Pre-literature review
- Problem Description
- Formulating RQ:S

2:nd Phase
- Literature Review
- Theoretical Framework
- Big Data Gathering
- Dataanalysis
- 2:nd Round Interviews
- Current State

3:rd Phase
- Model Propositions
- Model Testing
- Simulation
- Finished model

1.5 Method

This master thesis has been conducted as an opportunist case study performed at the earlier mentioned supplier Bosch Rexroth at their manufacturing facility located in Mellansel, Sweden. There were several different research methods that could have been used when gathering the empirical material relevant for this paper. The best way to obtain this in-depth material is through a case study. Case studies allow the possibility to generate the necessary empirical data and obtaining a better understanding of the complexity of the problem. A case study is the best way to provide the prerequisite needed to understand the reality of the complexity compared to other methods (Blomkvist & Hallin, 2015). According to Otley and Berry (1994) an opportunist case study is excellent when information from a particular person, business or other case is easily accessible.

Bosch Rexroth are suppliers of both single component and several systems of a more complex sort which makes them interesting to study and a good representative for a wide range of suppliers. The
reason why only one case study will be conducted is due to the fact that the results will be based on empirical data, gathered from a commercialized ERP-system. Therefore, one case study will be sufficient to make the results generalizable to enterprises who which to implement the same inventory policy and answer the research question. Bosch Rexroth have provided the necessary information and material to complete the case study. Data was gathered through their existing ERP-system. Wherefore the excel bolt-on was made to be compatible with the current ERP-system. This also provided the possibility to test the model on real data and analyze the results of the model.

1.5.1 Literature Review

The literature review was done in two parts, the first one to acquire the basic knowledge while the later would include more specific search to gain an in-depth knowledge that will be required for the project. During the project, smaller literature reviews was continuously made to stay updated with the latest research and to potential find new ideas that could be of use. The search was done using different searching engines such as; google scholar and primo (KTH:s library’s own search engine). The searches included terms as; inventory management, safety stock, dynamic safety stock, stochastic demand, forecasting, multiple items, ABC-classification. At google scholar the grand-father method was used, which according to Nuur (2015) is a good way of getting the primary sources.

If a search gave relevant results, the most cited one was used, and from there the relevant sources where used in order to get the foundation of the subject. Further on, to get the most up to date articles, the cited by function at google scholar was used.

1.5.2 Big Data

As the concerned problem consisted of almost 10’000 items, everyone with their unique product data, there is a big amount of data that has to be gathered and analyzed. To collect our data, we used several different methods depending on the data. Documentary analysis was used to gather data of historical demand and lead times. To get additional knowledge about the current inventory policy at Bosch Rexroth, a few observations on the warehouse was made. The observations were also used to investigate the possibility of increased inventory. Due to the availability and amount of collected data, the best method to analyze it is through within-case analysis (Collis & Hussey, 2013).

Data was gathered from their ERP-system and Insight. The latter is a system generating reports with data from their ERP-system.

To slightly reduce the complexity of the problem, data from 1’000 items could have been used instead and the results would thereafter have been generalizable for the rest of the population (Arvidsson, 2015). However, since all the data were available we still found it feasible to use all the gathered data rather than a randomly chosen sample to get the best results possible. In our case, the only difference would have been the time consumed to analyze and simulate rather than increased complexity.

1.5.3 Interviews

Initially unstructured interview was held with our supervisor at Bosch Rexroth to gather some initial information about the problem. Unstructured interviews are preferable in an early stage to get a deeper understanding of a complex problem (Blomkvist & Hallin, 2015). In a later phase interviews were held with chosen persons from both the order and material planning departments. These persons were chosen since they have been working at the company for a long time and were therefore expected to have more useful information and knowledge about the problem. Order department and material planning has contradictory purposes wherefore it is important to get the information from both sides. Order department wants to increase the inventory and reduce the sales
lead times to always be able to meet the incoming customer orders. Material planning department wants to reduce the costs of inventory, while having a high availability of raw material for the production. These interviews were held semi-structured as the purpose was to gain some more specific knowledge, complementing and confirming some gathered data from the ERP-system.

1.5.4 Spreadsheet Implementation

Even though several advanced simulation models for inventory control exist, spreadsheets are still well adopted to be used for optimizing the inventory control (Farasyn, et al., 2008; Liu, 2013). Spreadsheets are flexible and easy understandable which makes them suitable for a complement to the ERP-system, so called “Bolt-ons” (Farasyn, et al., 2008). The best spreadsheet simulation is adapted to the company specific case, wherefore there is no general optimal spreadsheet simulation (Liu, 2013). Farasyn et.al (2008) has for several years developed their bolt-ons for inventory control at P&G, they see several advantages with the usage of spreadsheets. Macros are useful when handling more complex situation while still getting a simple and user-friendly interface. However, they also suggest limiting the usage of Macros since the user can easily interpret the results as magic. Less usage of macros can therefore lead to further understanding of what is happening. Introducing new calculation techniques can drastically change the stock values, this will affect the employees trust in the calculation wherefore a validation is necessary. Farasyn et.al (2008) suggest a simulation to validate the approximations and calculations.

1.5.5 Simulation

Simulation is a great method for evaluating an inventory policy before putting it in to practice. Today there are many commercialized simulation software’s, for example Extend Simulation. The idée of using simulation is to evaluate the outcome of the new inventory policy before putting it to practice. By doing so it’s possible to identify weaknesses before it has negative impact on the enterprise availability. Simulation tools are often used to simulate the outcome of the theoretical findings in practice or simulating events and flows of either material or information in a supply chain. By using simulation before implementation the model can be verified and the results can be analyzed to see if it is fulfilling the initial requirements or if some after treatment needs to be done. (Chopra, 2013)

ExtendSim can be used to simulate simple and discrete events such as the car wash along with extremely complicated events with a lot of echelons influencing at different stages and uncertainty. It can be used to simulate the whole supply chain on a high level or zoomed in focusing on one single echelon and its activities. One of the greatest opportunities with using simulation is to investigate how a change in the supply chain will affect its overall performance. Even the slightest change may change the dynamics of the supply chain drastically. (Imagine That, 2013)

1.5.6 Validity, Reliability and Generalizability

Since many of the interviews were conducted with employees at Bosch Rexroth, we will have to consider the possibility of bias or political statements in the interviews. To identify and avoid these dilemmas we will triangulate the information gathered through the interviews with the data gathered through archive and observations in order to achieve high reliability. However, as the purpose is to develop the company, it should be in their interest to provide us with accurate information. Furthermore, the majority of the results will be based on archive data, which will decrease the risk of bias. As the main data gathering will be based on historical data which by definition is reliable and we will therefore focus on reaching high validity. To ensure validity, several simulation runs will be made to ensure that result is valid.
There are some facts that limits the generalizability, one is the assumption of normal distribution. It is also depending on the stock policy and inventory management of the company, although some parts of the results can be used and adapted to other companies. As they do not have a general way of calculation the safety stock in the corporate group, the result is intended to be reviewed for other manufacturing facilities.
2 Literature Review

In this section the basic theories about inventory theories, supply chain and safety stock will be introduced. Further on more update and state-of-the-art literature will be reviewed, in order to find different theories and solutions, feasible for the current problem.

2.1 Inventory Theory

The objective of this section is to provide the basic knowledge about inventory theory, how to control and calculate the stock levels. Furthermore, it should also bring some general knowledge regarding the classical and simpler problems. This knowledge should later on be extended with more sophisticated theory. The authors herein are well known in this area and have published several articles in this subject.

Inventory theory is one of the most researched subjects in production and industrial journals. Nevertheless, it is one of the most important concerning the trade-off between inventory cost and high service level (Nenes, et al., 2010; Gallmann & Belvedere, 2011). Logistics is most connected to its efficiency and effectiveness, the first one is most about total cost while the latter on is about the earlier mentioned trade-off. To gain more market shares and reduce the costs, industrial enterprises tries to, on one hand to increase the service level, which requires a higher safety stock. On the other hand, they try to decrease the capital binding by reducing the inventory, this is known as the dilemma of inventory management (Schmidt, et al., 2012). One of the characteristics in logistics services is stock availability, most commonly attributed by keeping satisfying inventory levels, including safety stock for the set service level, this can normally be addressed by proper formulas (Silver, 1991). These scientifically based formulas are made with different complexity and with different parameters. Large and medium-sized companies try to apply these scientific techniques in their inventory control. Although those techniques are based on theoretical assumptions which may cause an inadequate control system. The most commonly assumption is that the demand is based on a normal distribution or a poison distribution, which is not always the case in the reality (Nenes, et al., 2010; Kumar, et al., 2013). Another common problem is the large number of suppliers, articles and stock keeping units, which is mostly ignored by the academics. Basically there is two ways of achieving a higher service level at warehouse, one is by Warehouse Management and the other one is by Inventory Management seen in figure 1, where the latter one is subject in this report (Gallmann & Belvedere, 2011). A large number of articles requires a better performing warehouse management (Gallmann & Belvedere, 2011), although with non-homogenous demand, the inventory management is of most importance. It is also here companies tend to have the greatest focus as there might be major savings to achieve.
The main theories in inventory control have been subject for research since long. The general purpose of inventory control is to minimize the costs. Classically it has been done by researching the following questions Silver (Silver, 1981):

I. How often should the inventory status be determined, that is, what is the review interval?
II. When should a replenishment order be placed?
III. How large should the replenishment order be?

Even if these questions are stated more than 30 years ago, companies are still facing problems in these areas, since they are always eager to reduce costs. It is mainly the second two questions that will have an impact on the safety stock level. The relevant cost related to inventory are, replenishment costs, holding costs, shortage cost and system control cost, where the last one had been ignored a lot in theory (Silver, 1981). This is even more relevant today, as the used controlling systems are expensive. It can be argued for some more costs or irrelevant costs, or a redefinition of the costs. For example, the holding cost which is calculated per item, but Stadtler (2005) argues that it is more precise if it is counted based on the flow instead to get a more precise calculation. In his review, Silver (1981) sets up a framework to identify the character of the problem.

1. Single vs multiple items.
2. Probabilistic vs Deterministic demand
3. Single vs Multiple Periods
4. Stationary vs time varying parameters
5. Nature of the supply process
6. Replenishment Cost structure
7. Back orders vs lost sales
8. Shelf life considerations
9. Single vs Multiple stocking points

Figure 1: Parameters of investigation.
Marketing and manufacturing are mostly separated into different organizations. Where marketing is connected with increased revenues and manufacturing with reduced costs. This separation is done without considering the interactions and conflicts between those two departments, which might lead to increased costs (Karmarkar & Lele, 1989). When marketing are increasing the sales, manufacturing are supposed to be able to deliver those quantities. To be able to handle increased sales, manufacturing need to have either excess capacity or higher inventory (Karmarkar & Lele, 1989).

The delivery performance or service level is a measurement on how many percentages of the replenishment cycles that are having a stock out (Chopra, 2013). The perception of the service level differs from countries. While the marketing departments are out-located globally the manufacturing departments are located locally. To go from a service level from 95% to 100% is very costly, it requires a drastic increase in the safety stock level (Lutz, et al., 2003), see figure 2. Although, in some countries they expect a service level of 100%, if a delivery is not coming in time, it is the same thing as meaning the customer permanently lost, wherefore the whole sales group has to go together and apologize to the customer (Karmarkar & Lele, 1989).

Today’s production planning and inventory control is made in the ERP-system. ERP-systems are an extension and a more computerized version of the MRP-systems (Material requirement planning). Two parameters that sets the performance of the MRP-system is the safety stock and the lead time (Buzacott & Shanthikumar, 1994). One major factor that are influencing those parameters is the forecast accuracy during the lead time. Silver does not intend to solve the problem with forecasting, which according to Crocker et al. (Crocker, et al., 2012) is necessary, especially in stock control. A lot of focus in literature about MRP-system is about the lot sizes (Buzacott & Shanthikumar, 1994), although herein, we have not been optimizing the lot size even though it could have a great impact on the result.

Due to too the big variation of articles kept in stock other company specific problems occur. Those problems are partly solved in theory but there is a gap to practice (Silver, 1981). Also, when he did his review the ERP-system was not implemented in the wide range as it is today. This gap between theory and practice has been seen to increase over the years (Kumar, et al., 2013). The faculties strive for academic results with sophisticated models, which are based on unrealistic assumptions about the reality which makes the models less applicable. Another problem is that practitioners has to decide their pay off between data accuracy and data collection, which is not a problem for students as they are given the data (Kumar, et al., 2013).

Silver (1981) raised the importance of the question; “When should replenishments be done and in what quantities?"
To solve these problems, different stock policies can be used. To get the stock policies, there are 4 different denotations necessary, as we here in will call:

\[ r = \text{reorder point (also denoted ROP)} \]
\[ T = \text{review interval} \]
\[ Q = \text{order quantity} \]
\[ S = \text{Base stock level} \]

The combinations of these are normally \((r, Q), (r, S), (T, Q)\) and \((T, S)\). A policy of \((r, Q)\) means that when the inventory level drops under the reorder point \(r\), an order quantity \(Q\) is placed, this is the most common also known as continuous review (Chopra, 2013). On the opposite with periodic review policy of \((T, S)\) every review interval \(T\) an order from the current inventory level up to the base stock level \(S\) is placed, also known as periodic review (Chopra, 2013). The reorder point is set so the demand during the lead time will not exceed the inventory level (Kumar, et al., 2013; Chopra, 2013). This strategy is best with a continuous demand, with higher demand then expected there will be stock outs, which can be prevented by keeping a safety stock. The reorder point will then be \(r = E(D) + SS\). Where \(E(D)\) is the expected demand during the lead time and \(SS\) is the safety stock. For the order quantity there are several techniques to decide the optimal quantity, the most common is the \(\text{EOQ}\)-formula. There is also lot sizing techniques for the production planning, or discount version, although herein, the order quantity is fixed for every item. A policy of \((r, S)\) would be the same as a policy of \((r, Q)\) if \(Q = T - r\). There could also be an extension with policies of \((T, r, Q)\), every interval \(T\) check if the inventory level is below the reorder point \(r\) if it is below, then order \(Q\) (Kumar, et al., 2013).

### 2.1.1 Key performance indicators

The performance of the inventory can be measured in many ways. Beamon (1999) has listed nine examples of supply chain output performance measurements: (1) sales, (2) profit, (3) fill rate, (4) on-time deliveries, (5) backorder/stockout, (6) customer response time, (7) manufacturing lead time, (8) shipping errors and (9) customer complaints. Some of these measurements can however not be traced to the safety stock and is therefore not relevant in this case. According to Beamon (1991) the measurements significant for the safety stock is profit fill rate, on-time deliveries, backorders and customer response time. However, some of these measurements are only relevant for products that are sold as items and thus not have a production lead time. By measuring the fill rate the amount of orders that are delivered in time can be evaluated. To evaluate the condition of the inventory the best way is to measure the inventory turnover (Mattsson & Jonsson, 2003).

The order fill rate measures the percentage of orders that is delivered straight from the shelf during a pre-defined period compared to the total amount of orders. The period is defined over a specified numbers of orders, replenishment cycles or over a specified amount of demand rather than time. Using order fill rate as a KPI is important when the customer value that the entire order is being filled simultaneously. (Chopra, 2013)

The product fill rate on the other hand measures the fraction of products delivered immediately from available inventory and thus do not take a multiproduct scenario in to account. The product fill rate is by definition higher or equal to the order fill rate. Therefore, measuring this KPI can be misleading if the order is only delivered when it’s complete rather than split it up. Measuring the product fill rate however gives a better view of which items that more frequently run out of stock so that the
organization can behave accordingly and increase the inventory levels on critical items. The product fill rate is measured the same way as the order fill rate, over a pre-defined period. (Chopra, 2013)

The inventory turnover can be measured in two different ways. The first method measures the efficiency of the inventory policy by measuring the fraction between the delivered value, which is the same as cost of goods sold, and the average inventory cost. The second method measures in how many days the inventory turnover. An inventory turnover of two days means that the whole inventory is sold and replaced every other day or 175 times per year. The inventory turnover measuring the fraction is defined as:

\[
\text{Inventory turnover} = \frac{\text{Cost of goods sold per time unit}}{\text{Average inventory cost per time unit}} \quad (\text{Mattsson & Jonsson, 2003})
\]

An alternative way is to instead look at the turnover in number of days which is defined by:

\[
\text{Inventory turnover in days} = \frac{365}{\text{Inventory turnover}} \quad (\text{Weygandt, et al., 1996})
\]

The customer response time is the amount of time between the delivery and its corresponding demand date. The customer response time is closely related to the fill rate but also takes the amount of days in to account while the order fill rate is a binary measurement. The drawback of this method is that an order that is one month late is treated equally to an order that is only one day late. If the number of days is of more importance than the number of order, measuring the customer response time would be preferable. (Beamon, 1999)

SCORE is a council who has been working with standards in supply chain performance. They suggest that the best way to evaluate a supply chains performance is to measure their reliability and responsiveness. The best way to measure the reliability is to look at the forecast accuracy, delivery performance to customer request date and the fill rate. While the best way to measure a company’s responsiveness is to measure the cumulative source or the make cycle time. (SCORE, 2001)

There are mainly four different planning strategies, Make-to-Stock and Make-to-order, Engineer to order and project business. A make-to-stock strategy indicates that the organization are manufacturing and assembling products following a forecast. A Make to order strategy on the other hand manufactures the components necessary to create the products but waits with the assembly until a customer order is made. When Engineer-to-order strategy neither the manufacturing or assembling is made based on forecast, instead the manufacturing is made after the customer order has been made. The project business strategy is when the organization is not storing any inventory at all. The raw material is purchased only after a customer order has been made. (Rajagopalan, 2002)

2.1.2 Planning strategies

The different strategies have their advantages. Depending on the strategy of choice a company can offer a faster responsiveness but at the cost of carrying a larger inventory. The strategy of choice should be closely connected to the overall business strategy. These different strategies are connected to where the organization choice to have their decoupling point. The decoupling point is demonstrated by the location in the supply chain where the product is linked to a specific order. No inventory is stored in the supply chain after the decoupling point. A graphical illustration of the different strategies linked to the decoupling point can be found in the figure below. (Gupta & Benjaafar, 204)
2.2 Supply chain

The term supply chain along with supply chain management is frequently used both academically and in practice. The meaning of the term is however still unclear, different authors use different terminologies and definitions (Cooper, et al., 1997). Despite the increased popularity there still remains some confusion when it comes to the meaning of the terms (Tyndall, et al., 1998). To avoid any confusion, the definition we will follow will be the one Baemon (1998) suggested in his work:

“A supply chain may be defined as an integrated process wherein a number of various business entities (i.e., suppliers, manufacturers, distributors, and retailers) work together in an effort to: (1) acquire raw materials, (2) convert these raw materials into specific final products, and (3) deliver these final products to retailers. This chain is traditionally characterized by a forward flow of materials and a backward flow of information. For years, researchers and practitioners have primarily investigated the various processes of the supply chain individually.” (Beamon, 1998, p. 1)
Mentzer et al. (2001) have identified three degrees of complexity of a supply chain network. The different complexities are named: “direct supply chain”, “extended supply chain” and “ultimate supply chain”. The direct supply chain is the category with the least complexity. It consists of an organization in the center which has one supplier and one customer. An extended supply chain includes the same center as the direct supply chain but with an extent that both the supplier and their customer have an immediate supplier and immediate customer respectively. The ultimate supply chain consists of all organizations involved in the flow of resources. A graphical description can be found in figure 3.

There are mainly two different ordering policies: (1) installation stock and (2) echelon stock policies (Diks, et al., 1996). Both of these terms are also known under different names. The installation stock policy is also known as single-echelon and the echelon is also known as multiple-echelon. There is however no difference between these two theories other than their names. It’s worth mentioning that an echelon is defined as one stock-point in the supply chain, also known as a node. We will in this paper refer to the terms single and multiple-echelon and therefore exclude the terms installation and echelon stocks. The difference between this ordering policies is that the multiple-echelon stock policy does not only take its in-house inventory in consideration but also all the remaining echelons inventories downstream. The multiple-echelon concept was first introduced by Clark & Scarf (1960). Diks et al. (1996) is one of many who have expanded this initial research in expectation to improve it and clarify any confusion. In their work they suggested two different definitions of the echelon stock policy. The difference between them is that one takes all stock in to account, both stock available at each echelon point and in transit while the other only takes stock on hand and in transit into account. The two suggested definitions are as follows:

---

**Figure 4: Graphical description of the three different supply chain complexities (Mentzer, et al., 2001)**

---

---
“The sum of all planned orders at this stock point plus its physical stock plus that in transit to or on
hand at its downstream stock points minus eventual back orders at its end-stock points”. (Diks, et al.,
1996, p. 4)

“All stock in transit to this stockpoint plus its physical stock plus that in transit to or on hand at its
downstream stockpoints minus back orders at its end-stockpoints”. (Diks, et al., 1996, p. 4)

These definitions look similar but can in practice give two separate material flows depending on the
enterprise replenishment policy. A continuous review policy will give the same results regardless of
the definition. If the stock policy on the other hand is a periodic review, these definitions might lead
to different material flows depending on when the replenishment order is revived. The difference
will occur when the replenishments orders are received between two reviews. To avoid this
dilemma, Diks el al. (1996) suggests the later mentioned definition.

The installation stock policy on the other hand dose only take inventory directly associated with the
echelon in focus. Installation stock policy could therefore be defined as;

“The inventory position is defined as the sum of all planned orders at this stock point and its physical
stock minus its back orders.” (Diks, et al., 1996, p. 4)

The installation stock policy has a clear advantage that it does not require any further information
about the inventory situation other than information with a direct connection to its own stock point.
This information is easy to track. However, this also leads to a clear disadvantage when it comes to
efficiency. Due to the lack of knowledge about the whole system the cost effectiveness of using the
installation stock policy is limited. Plenty of studies has been made regarding the added value of
According to several reports, the installation stock policy is superior for distribution systems with
high order set-up cost (Lee & Moinzadeh, 1987; Axsäter, 1993; Moinzadeh & Lee, 1986). Axsäter &
Rossling (1993) also proved in their work that the echelon stock policy is superior to the installation
when the replenishment order policy is done with continuous review.

By definition, the echelon stock policy may also reduce the amplitude of the bullwhip effect. Echelon
stock policies are however more difficult to implement the further upstream in a supply chain the
echelon is located due to the increased information and communication necessary to handle.
However, Axsäter & Rossling (1993) proves in their work that all installation stock policies can be
duplicated by an equivalent echelon stock policy. An echelon stock policy on the other hand can only
be replaced by an equivalent installation stock policy if the policy is nested for all demand sequences.

The supply chain is build up from five primary processes; inbound logistics, operations, outbound
logistics, sales and marketing and service.

• **Inbound logistics** – Processes included in the inbound logistics category are activities
  associated with receiving, storing and spreading the necessary inputs to the product.
  Examples of such activities are; material handling, warehousing and inventory control.
• **Operations** – Refers to activities associated with creating the final product from its inputs.
  Activities involved in this category are activities such as; machining, packaging, assembly and
testing.
• **Outbound logistics** – The outbound logistics is activities that are connected with collecting,
  storing and getting the product to the buyer. Finished goods warehousing, material handling
  and order processing are a few examples of these kinds of activities.
• **Sales and marketing** – When used within a supply chain context, the activities involved in
  these process are; promotions, channel selections and pricing.
- **Service** – Under the service process one can find activities associated with enhancing or maintaining the value of the product. These involve installation, repairing, parts supply and training.

By closely managing and analyzing these five processes a company can become more profitable, hence gain an increased competitive advantage (Porter, 1985).

Managing a company’s supply chain is difficult and complex (Blanchard, 2010). Hofman (2004) analyses which supply chain factors top-performing companies have in common. She observed that the best-in-class companies share three different traits which is the key to their success no matter the industry they operate in:

1. **Aiming for balance** – Companies with top performing supply chains is not necessarily the very best in every category. Instead they are focused on being good enough in all areas, which in the end adds up to be best-in-class.

2. **Increased demand visibility** – Having a forecast with a high level of accuracy is the key to getting perfect order fulfillment, which in the end provides excellent customer service.

3. **Isolation of high costs** – State of the art companies know where they are holding high costs and the reason for holding these costs. By possessing this knowledge, these companies know where they should focus their best practices and technology investments. (Hofman, 2004)

Depending on the organization, companies can choose to have different supply chain strategies when it comes to responsiveness. Top performing supply chains have a clear supply chain strategy that aligns with their business strategy. Take Walmart for example, they provide a wide range of products at a low price. To accomplish this strategy, they have to minimize the supply chain costs by working with long replenishment lead times at large quantities, which results in a reduction in their responsiveness. 7-Eleven on the other hand focus on offering high responsiveness with several replenishments per day. The results of this strategy is high product availability but at an increased cost. Figure 4 illustrates a graphical representation of the tradeoff between responsiveness and cost. The optimal supply chain policy for any company can be illustrated as the frontier in the graph. Companies that perform under this line have a sub-optimal solution and should seek to either improve their responsiveness or reduce their costs. (Chopra, 2013)

In addition to this, Blanchard (2010) presents in his book a checklist that provides a basic assessment over the performance on the supply chain. If the answer is no, or unsure about the answer, to any of these questions then it’s about time to improve the supply chain.

1. Does your order fill rates meet management’s specific and measured customer service strategy?
2. Are your delivery lead times competitive and predictable?
3. Do all of your supply chain departments agree on which products are make-to-stock and which are make-to-order?
4. Do sales and manufacturing share equally in determining the mix and investment in inventory?
5. Are the appropriate calculations being used rather than rules of thumb to establish the desired mix and levels?
6. Are management’s inventory investment plan and customer service objectives being compared against the actual results that are achieved?
7. Are short-term forecast deviations being monitored and adjusted, and is long-term forecast accuracy continuously improving?
8. Is your inventory accuracy consistently above 98 percent?
9. Are you able to avoid carrying excess safety stock buffers?
10. Are your excess and obsolete inventories being measured, and are they less than 1 percent of total inventory?

(Blanchard, 2010)

Lee & Billington (1992) have identified fourteen common pitfalls when managing the supply chain. The pitfalls are related to information sharing, supply chain management, operational problems, strategy and design. Some of these pitfalls are however not relevant when analyzing the safety stock and have therefore been excluded from the list below.

1. **No Supply Chain Metrics**
   The first pitfall is related to the supply chains overall performance and highlights the importance of working together to achieve a common goal. Often, organizations choose their supply chain strategy without considering other echelons in the supply chain. As an example Lee & Billington (1992) mentioned a scenario where one stage of the supply chain focuses on lowering their total inventory levels since this directly influenced their revenue. What they did not consider however was how this would influence their responsiveness and fill rate to the next stage in the supply chain.

2. **Inadequate Definition of Customer Service**
   Measuring the customer service is highly important which most organizations are aware of. The problem however is how to measure it. The customer service can be measured in several ways. What measurement that is of most interest very depending on the customers’ expectations. One common KPI is the order fill rate; this measurement does however not provide the information of what happens with the order that is not delivered on time. Therefore, a complementary measurement would be to measure the total order cycle time or total response time. Another aspect is what caused the order to not be delivering on time. Measuring the order fill rate may not itself diagnose the operational problems.

3. **Inaccurate Delivery Status Data**
   This pitfall rises the problem with not providing the customer with accurate delivery status, this is especially important for orders which is delivered after the due date. Many companies provide their customer with standard response time, although this may not resemble the actual response time.

4. **Inefficient Information System**
   Information sharing can also be a problem inside of the organization. Providing necessary information which is up to date and accurate is the key to avoid of overstocking or backorders. An extreme example of this is a northern California PC manufacturer that manufactured after the material requirements planning (MRP) system. The MRP was done on a monthly basis since longer planning cycles increased the forecast error. However, due to inefficient information sharing the manufacturing ends up assembling the wrong products. This error leads to increases in both inventory levels and backorders.
5. Ignoring the Impact of Uncertainties
There are many sources in a supply chain that is uncertain, e.g. the replenishment lead time, manufacturing process time, demand and the quality of incoming goods. In order to reduce the impact of these uncertainties the supply chain manager must first understand their source and their significance. Many organizations fail to document and track these variables which consequently lead to overstocking on some items while understocking on others. Some organizations adopt well to uncertainties but lack routines for eliminating them. Classic example is when the purchasing managers frequently modify their inventory stocking policies to avoid stockouts during manufacturing but do nothing to improve their suppliers’ delivery performance which in many cases is the root cause of the problem.

6. Simplistic Inventory Stocking Policies
Over time the previous mentioned uncertainties will change and will therefore require periodic update. Furthermore, organizations commonly use generic stocking policies rather than linking their stocking policies to the sources of uncertainties that required inventory in the first place. An example of a generic stock policy is to categorize items after transaction volumes in categories A, B and C. A classification of this kind does not necessarily reflect their level of uncertainty.

7. Discrimination against Internal Customers
A common mistake is to only measure the external customers’ service and satisfaction even though delays between internal units could create significant inventory and backorder problems. To achieve high external satisfaction, organizations must also value and consider their internal customers.

8. Poor Coordination
If a customer order consists of multiple items and these items needs to be delivered at the same time, company will need to merge these items before shipping. If these items are stored in different divisions, these divisions need to be coordinated in order to deliver the package in time. Poor coordination in this aspect leads to delayed deliveries and backorders. As the supply chain becomes more globalized and consists of more units the coordination becomes more critical.

9. Incomplete Shipment Methods Analysis
When considering alternative methods of transportations, the final decision is in many cases mostly based on financial effects. However, it’s important to also consider the operational factors when deciding the shipment methods. For example, a company might get large saving by changing delivering method from shipping to flying. Even though the shipping by airplane is more expensive the organization can make significant savings due to the decreased delivery lead time thus reduce uncertainty.

10. Incorrect Assessment of Inventory Costs
When analyzing the total inventory cost the opportunity cost has to be estimated and considered as well. However, there is no industry standard how the opportunity cost should be estimated in practice. Common used costs are; cost of capital, warehousing and storage. Some costs that organizations tend to forget is obsolescence or cost of replacing the inventory due to changes in design. These costs are necessary to consider when working with products with short life cycles or fixed shelf lives.

11. Organizational Barriers
In some cases, units in a supply chains can be part of different divisions of an organization and therefore have its own performance measurements and evaluation responsibilities. These organizational barriers may prevent the possibility to create an inventory control policy that
increases the supply chains surplus. Pitfall four and eight are exhibits of such barriers. Most large manufacturing companies have decentralized organization structure which often results in these type of barriers.

12. Incomplete Supply Chain
Manufacturers often measure the fill rate to evaluate the responsiveness to the customer demand. The customer demand in this case could however refer to orders made from retailers or other echelons in a supply chain and not the end customer. It is suggested to go beyond the internal supply chain by also including the external suppliers and customers. Understanding your customers’ inventory control system is the only way to accurately set internal service targets.

2.3 ABC-Classification
The ABC classification is a ranking method based on the economist Vilfredo Pareto theories that a small percentage of the population corresponds to the majority of its output. Pareto’s theories has evolved during the years and also made more generalizable to other contexts but his 80-20 rule remains the same (Benito, et al., 1986). The ABC classification is today frequently used within organizations as an analytic tool for inventory control. The classification is used as a tool to identify and grouping items based on how useful they are for achieving the business goals (Rouse, 2011). The reason for this is that in most practical cases organizations are working with a large number of different items which makes it impossible to manage on specific level. Therefore, ABC classification is used to easy determine which of the items that needs higher degree of attention and which ones that needs less. The classical ABC classification group the items based on demand value and the demand volume (Ernst & Cohen, 1990). The ABC classification tool splits the inventory items into three groups; A, B and C depending on previous mentioned criteria.

- Class A which typically is 20% of the items and 80% of the sales value.
- Class B which typically is 30% of the items and 15% of the sales value.
- Class C which typically is 50% of the items and 5% of the sales value.

(Teunter, et al., 2010)

The final decision depends on the management valuation of the trade-offs between the amount of items classified as the higher classes and the sales value. A graphical illustration of the different groups can be found in the figure below.

The different categories all need different management and serviceability due to the difference in volume. An item with A-classification generally needs to have a high degree of management and to be reviewed constantly. Whilst the other groups can be less reviewed, in particular the C-classification can be ordered in higher volumes and be stored for a longer period (Teunter, et al., 2010).

As an addition to the basic ABC classification, Flores & Whybark (1986) argues that the most important criteria can vary between organizations and which part of the organization that is concerned. Therefore, they suggest a modified ABC classification using what they call a multi-criteria ABC analysis (MCAA). Obsolescence, lead time, substitutability, repair ability, criticality or commonality is examples of other criteria that could be of concern. The method for using this analysis is to firstly identify the critical criteria that are of interest. Secondly is to map these criteria towards the dollar usage by using a 3x3 matrix. Figure 5 shows an example of such a matrix.
The matrix is then later used the same way as the ABC classification to determine the level of attention for each item. To determine the group of classification the item needs to be on the diagonal of the matrix. The objective is therefore to reclassify the items so that all items ends up in the diagonal. Usually this is done by weighting the different criteria to determine the final classification. For instance, items with long lead times and high dollar usage should have the highest priority, which is closely related to the previous class A group. While the items with low dollar usage and short lead times needs less degree of management like the classical C classification. Furthermore, this method can be used several times with different critical criteria to finally determine the appropriate level of attention. Different theories suggest to extend the matrix to three dimensions and to reclassify the items to the main diagonal whenever it’s possible. Each criterion used increases the complexity of the classification. If all criteria are classified as important, this task may be very hard. In some cases, using more than two criteria is not desirable. Even using two criteria can be a difficult task (Flores & Whybark, 1986). To simplify this process different studies has presented a strategy to first use a cluster analysis to group similar items before using the MCAA. (Cohen & Ernst, 1988; Ernst & Cohen, 1990)

All the mentioned methods so far have been consisting of a classification based on three categories, resulting in a 3x3 matrix. This is necessarily not always the case, different studies have been discussing the possibility to extend the number of categories to get a more accurate ranking. The number of classes when using the MCAA should however be limited to six. (Graham, 1987; Silver, et al., 1998)

It has been generally recognized that the traditional ABC classification may not provide as good classification of inventory items in practice. Therefore several studies have been made to develop an alternative method which will provide better results when used in practice (Guvenir & Erel, 1998; Huiskonen, 2001). E.g. Zhou & Fan suggest the use of weighted linear programming when determining the classifications. The advantage of using linear programming is the objectiveness when ranking the MCAA (Zhou & Fan, 2007).

Zhang et.al. (2001) suggest a modified multiplied criteria analysis where only one single criterion is sufficient. The criterion is then calculated using the formula 3.1 which is based on demand, holding cost, and replenishment lead time, rather than previous methods where two or more values where compared in a matrix. The suggested model is however not producing gains in terms of inventory
cost reductions nor increased service level compared to the first mention classification method, but is much easier to implement in practice (Teunter, et al., 2010).

\[
\frac{D_i}{h_i^2 L_i} \quad (2.1)
\]

Where \(D_i\) is the expected demand for item \(i\) per year, \(h_i\) is the unit holding cost for item \(i\) and \(L_i\) is the replenishment lead time for item \(i\). To evaluate the group, each item is later ranked in descending order depending of the value from equation 2.1. The first 20% of the items with the highest value is allocated class A, the following 30% class B and the remaining 50% class C. Where items of class A will be given the lowest service, class B will be given moderate and class C will be given the highest service.

More recent studies have extended the previous mentioned method and accomplished to improve it with respect to minimizing inventory costs while maximizing service level. Their enhanced formula does not only take the inventory holding cost and demand during the timer period, but also shortage cost and average order quantity. The criterion can be calculated according to equation 2.2. (Teunter, et al., 2010)

\[
\frac{b_i D_i}{h_i Q_i} \quad (2.2)
\]

- \(b_i\) is the backorder penalty cost for item \(i\).
- \(D_i\) is the demand per unit time for item \(i\).
- \(h_i\) is the inventory holding cost for item \(i\) per time unit.
- \(Q_i\) is the average order quantity for item \(i\).

The method then follows the same procedure as Zhang et al. (2001) except for the fact that this method is not limited to three classes. The number and size of each class may vary depending on the situation, as mentioned before the manager evaluate the trade-offs. Although it’s suggested to have an increasing class size with decreasing service level. Numbers such as 20%, 30% and 50% for three classes (ABC) and 4%, 7%, 10%, 16%, 25% and 38% for six classes (ABCDEF) gives good results when used for both Zhang et.al (2001) and cost criterion analysis. (Teunter, et al., 2010)

The results of Teunter et.al (2010) studies shows that their Cost criterion and Zhang et al. criterion analysis performs significantly better then when only looking at the Demand value or Demand volume when using both three and six classes. Figure 6 shows the summarized results of two different data sets. The data set to the left is from a warehouse supplying spare parts and the data set to the right is from a retailer that sells do-it-yourself products. Both data sets are based on the assumptions that the demand is normal distributed.
However, the drawback of the Cost criterion model is that it’s based on the backorder penalty cost. Which in practice can be very difficult, if not impossible, to determine, especially on an item specific level (Nenes, et al., 2010; Chopra, 2013). When the backorder penalty is difficult to estimate, Chopra (2013) suggest an implied evaluation, based on the inventory policy. If all the unfilled demand is backlogged, the implied cost can be evaluated using formula 2.3. If the evaluated cost provided by this method gives an unrealistic high or low value, they argue that the organization in this case are most likely carrying too much or less inventory respectively.

$$b = \frac{hQ}{(1-CSL)D} \quad (2.3)$$

The ABC-classification greatly used when deciding the CSL. Items will be given different cycle service levels depending on the classification group. In the following chapter different theories and the practical usage regarding CSL will be described.

### 2.4 Safety inventory

Safety inventory is mainly used to avoid stock outs during the replenishment cycle and maintain a higher service level. The safety inventory, also known as the safety stock, will assure that there will be no stock outs during the replenishment cycle due to variance in the demand. The general calculations are though based on the assumption that the demand is following a normal distribution and the mean value and the standard deviation are known. Coordinating the safety stock can lead to cost saving of more than 15 % (Kelle, 2005). Class A items should have medium safety stock level for critical items, Class B items should have large safety stock for critical items and class C should have low or none. (Benito, et al., 1987)

#### 2.4.1 Service level (CSL)

The CSL is the percentage of the replenishment cycles that results in all of the customer demand being met. The replenishment cycle is the time between the arrivals of two replenishments. In other words, CSL is the probability that a stock out will not occur during a replenishment cycle. The CSL should not be mistaken with the order fill rate, which is the fraction of orders that are filled from available inventory. When an order contains more than one product, an order is filled only when all of the products on the order can be supplied from available inventory. The product fill rate on the other hand measures the probability that a single product will be supplied from available inventory and thus do not take multiproduct scenario in to account. The order fill rate, CSL and the product fill rate should all be measured over a specified numbers of orders, replenishment cycles or over a specified amount of demand rather than time. (Chopra, 2013)
2.4.2 Statistical variables

To understand the mathematical calculations used for the derivations some statistical methods are needed. Therefore, this section will briefly define the most used statistical variables, mean value, variance and the standard deviation. The definition is the same for each variable no matter the distribution but the method for calculating the variables may differ depending on the type of distribution.

The mean value is given by the average value of the population. The calculations are done by summarizing all the numbers and then dividing the sum by the total number of data points given by the population. For a discreet variable the mean is given by formula 2.4. The standard deviation however is a more complex measurement and vary depending on the type of distribution. For continues distribution variable the standard deviation is given by equation 2.5. The standard deviation indicates the spread of the data. A low standard deviation indicates that the data points tends to be near the mean value, while a high standard deviation indicates a wider spread. The standard deviation is also defined as the square root of the variance, which tells us that the variance can be calculated by squaring the standard deviation. (Raykov & Marcoulides, 2012)

- $\mu$ is the mean value
- $X_i$ is the random variable
- $P(X_i)$ is the probability for the outcome $X_i$

$$\mu = \sum X_i * P(X_i) \quad (2.4)$$

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (X_i - \mu)^2} \quad (2.5)$$

For a discrete random variable the standard deviation is instead given by equation 2.6. (Berenson, et al., 2012)

$$\sigma = \sqrt{\sum \{(X_i - \mu)^2 * P(X_i)\}} \quad (2.6)$$

Another variable of interest is the relative standard deviation which is simply given by the fraction between the standard deviation and its mean value. The relative standard deviation (RSD) is useful when analyzing the relative spread for a population. A high RSD indicates a large spread while a low indicates a smaller spread. RSD is however not an appropriate measurement when the mean value is close to zero since a small change will in this case give a large change of the output. (Everitt, 1998)

In some cases, it might be necessary to aggregate the statistical variables. The reason might be that you store an item at different location which then provides two mean values and two standard deviations even though it’s the same item. When it comes to the mean value the aggregated mean value is calculated the same way as if the measurement was two individual populations. (Raykov & Marcoulides, 2012)

$$\mu_a = \frac{1}{N} \sum_{i=1}^{N} \mu_i \quad (2.7)$$

The standard deviation is however more difficult to calculate. The standard deviation is calculated by first converting the standard deviation to the variance for each value, and then summarizing the variances. Lastly the standard deviation can be generated by taking the square root of the variance. (Raykov & Marcoulides, 2012)
\[ \sigma_a = \sqrt{\sum_{i=1}^{N} \sigma_i^2} \quad (2.8) \]

Important to acknowledge is that by definition the RSD is limited depending on the number of data points. Measuring the RSD during a year on a monthly basis, the RSD cannot exceed 331.6625 %. With a weekly basis this number is 728.0110 % and with a daily 1907.8784%. These numbers can easily be calculated by assuming all data points to be zero except one.

### 2.4.3 Derivation of the safety stock model

SERV1 and SERV2 are the basic derivations of the safety stock. Although, they are not always giving a good payoff for the dilemma of inventory management mentioned earlier. Therefore, there has been a lot of extensions and renewing of those formulas in order to have more accurate calculation. Dynamic models are the most lately approach to receive a good pay off.

SERV1 one is the most common approach in the way of calculating the safety stock. This is based on the replenishment cycle, and calculates the possibility of having a stock out during this time. (Olhager, 2000) However this way of calculating the safety stock level does not take into account the depth of the stock outs. The formula is based on the assumption that the demand is a stochastic variable with a normal distribution, \( N(\mu, \sigma) \).

The possibility of no stock out during the replenishment cycle is:

\[ SERV1 = P(\text{no stock out}) = P(D \leq r) = P \left( \frac{D-\mu}{\sigma} \leq \frac{r-\mu}{\sigma} \right) = \Phi \left( \frac{r-\mu}{\sigma} \right) = \Phi \left( \frac{SS}{\sigma} \right) \quad (2.9) \]

Where:
- \( D = \text{Real demand during the replenishment cycle} \)
- \( r = \mu + SS \)
- \( SS = \text{Safety Stock} \)

This gives us the following:

\[ SS = \Phi^{-1} \left( SERV1 \right) \sigma = k \sigma E(Lt) \quad (2.10) \]

Where:
- \( k = \text{safety factor} \)
- \( E(Lt) = \text{Expected Lead time} \)

The safety factor \( k \) is the inverse of the set service level of the normal distribution and can be calculated according to equation (2.11)

\[ k = \text{NORMSINV}(CSL) \quad (2.11) \]

According to Chopra (2013) the CSL can then be evaluated as; the probability of not running out of stock in a replenishment cycle. Using this knowledge for the replenishment policy continuous review, the CSL can be described as:

\[ CSL = \text{Prob}(\text{demand during lead time of } L \text{ weeks } \leq \text{ROP}) \quad (2.12) \]
If a normal distributed demand is assumed, with a mean demand of $D_L$ and a standard deviation of $\sigma_L$ during the lead time $L$, equation 2.12 can be rewritten as:

$$CSL = F(ROP, D_L, \sigma_L) = NORMDIST(ROP, D_L, \sigma_L)$$ (2.13)

### 2.4.4 Fill rate

SERV2 in comparison to the SERV1 takes also into account the depth of the stock outs. This means that it is both taking into account the number of stock outs as well as the total amount of products in each stock out. This concept is more known as the service fill rate. This does not take into account the importance of the order quantity but it can be more accurate depending on the circumstances especially if split up orders can be accepted (Olhager, 2000). To calculate the safety stock levels for a desired service level, numerical tools are needed (Chopra, 2013). Although it can be used the other way around as the CSL usually is a measurement set by the organization in order to achieve a desired fill rate. The fill rate is generally a more relevant measurement when evaluating customer satisfaction and estimating the fraction of demand that is delivered in time, given that the demand can only be satisfied from items in stock. The two measurements are however closely related since increasing the CSL will result in greater fill rate. The fill rate can be evaluated as the possibility that no stock out occurs during a replenishment lead time, which can be translated in to equation 2.14.

$$fill\ rate = 1 - \frac{ESC}{Q} = (Q - ESC)/Q$$ (2.14)

Where ESC is the expected shortage during a replenishment cycle and Q is the order quantity. If once again a normal distributed demand is assumed, with a mean demand of $D_L$ and a standard deviation of $\sigma_L$ during the lead time $L$ the calculations of ESC can according to Chopra be simplified as:

$$ESC = -(ROP - D_L)\left[1 - F_s\left(\frac{ROP - D_L}{\sigma_L}\right)\right] + \sigma_L f_s\left(\frac{ROP - D_L}{\sigma_L}\right)$$ (2.15)

Where $F_s$ is the standard cumulative and $f_s$ is the standard normal density functions. This in turn gives us formula 2.16.

$$ESC = -(ROP - D_L)\left[1 - NORMDIST\left(-\frac{ROP - D_L}{\sigma_L}, 0,1,1\right)\right] + \sigma_L NORMDIST\left(-\frac{ROP - D_L}{\sigma_L}, 0,1,0\right)$$

(2.16)

In most practical cases the CSL is decided by the management of the organization in such way that the product achieves a desired fill rate. That said, the order fill rate is in many cases higher than the CSL and the product fill rate is higher than the order fill rate when a firm is selling multiple products. Tracking the order fill rates is important when the customer value that the entire order is being filled simultaneously (Chopra, 2013). If the target level is too high, there is no automatic procedure to decrease the inventory levels. In this scenario the enterprise will continuously carry a high inventory (Farasyn, et al., 2008).

As mentioned in the previous chapter ABC classification is a useful tool for determining the desired CSL for each item. If looking back at the classical ABC classification, items of class A would then be
given the lowest CSL followed by class B and so on. It’s important to mention that when using the classification method by Zhang et al. (2001) or the cost criterion method by Teunter et al. (2010), items of class A should be given the highest CSL rather than the previous suggested method. The specific number for each class may vary from case to case depending on the desired trade-off between fill rate and inventory costs. Although the lowest feasible CSL is 50% since every value below that will by definition give the same safety stock. Increasing the CSL from 95% to 99% will result in higher cost, while the fill rate increases at a much slower pace. Keep in mind that increasing the CSL consequently increases the ROP. This will in turn increases the average number of items in stock, thus increases the inventory cost given that the demand remains unchanged. (Chopra, 2013)

Zhang et al. (2001) has presented an algorithm for finding the most feasible SCL distribution between each class that minimized the inventory cost. The algorithm involves to first start with a giving class A as low CSL as possible and class C as high as possible. Next step is to search for the lowest feasible CSL for class B that achieves the desired average fill rate for all items. The comparison between different solutions can be done by fixing CSL for class A and C at different values and then find the optimal C as previously suggested. (Zhang, et al., 2001)

The difference between the ROP and the expected demand during the replenishment time is also known as the safety stock (SS) (Chopra, 2013). The following chapter will therefore further explain the SS concept, describe different theories as well as explain how it corresponds to the organizations achievements.

2.4.5 Update frequency

How frequently an inventory policy needs and should be updated to stay accurate depends on the demand pattern. When the demand pattern is seasonal the inventory policy, including the safety stock, should be adjusted accordingly over the year. In some extreme cases this can mean that the policy needs to be updated every week during some periods of the year. (Chopra, 2013)

According to Benito et al (1987) the ABC classification should be reclassified once or twice a year depending on the items classification. Items from category A or B should be reclassified every sixth month while items with C category only needs to be reclassified every twelfth month.

The safety stock needs to be updated more frequently if the expected demand changes drastically. These updates should however only be done if there is an explanation behind the changes. For example, due to macro-economic reasons such as financial or oil crises. If the drastic change does not have a logical explanation the change in demand could be explained by the normal deviation and it might still follow the same demand pattern as before. Meaning the rest of the year will go back to the same level of demand. (Li, et al., 2006)

2.4.6 Safety stock in practice

Even though a lot of studies have investigating different safety inventory policies with different approaches there still remains a gap between theory and how it’s used in practice. This section will highlight some of these gaps and also suggest different approaches to reduce them. (Silver, 1981)

In practice, a company usually places an order in larger lots then one unit. Therefore, the demand observed by different stages of the supply chain tends to be lumpy. When using a continuous review policy, lumpiness may lead to the inventory dropping below the ROP before a replenishment order is
placed. The literature shows that the inventory will on average drop below the ROP by half the order size. To overcome the lumpiness, the safety inventory can be raised, as a suggestion by half the average order size. The safety inventory is usually a large fraction of the total inventory cost. The ability to reduce the safety inventory without compromising the availability can significantly increase the supply chain performance. (Chopra, 2013)

Before putting an inventory policy into practice, simulation is an effective way to evaluate the performance. Today there are many commercialized simulation software’s, e.g. Extend Simulation. The idea of using simulation is to evaluate the outcome of the new inventory policy before putting it to practice. By doing so it’s possible to identify weaknesses before it has negative impact on the organizations availability. If the simulation run does not show any weaknesses, the policy can be implemented. In order to avoid piling up to large inventory in the implementation face of a new inventory policy, it is suggested that companies start with a pilot program of products that are representative of the entire set of products in the inventory. Monitoring a supply chain allows to make adjustments if a policy is not working as intended. (Chopra, 2013)

2.4.7 ExtendSim

ExtendSim is as mentioned earlier a simulation software used for modeling discrete event, continues, agent-based or discrete rate processes. ExtendSim can be used for modeling manufacturing, supply chain, reliability or other flows of either material or information. The software is based upon six different libraries which in turn contains multiply blocks used for different purposes. The user then links these blocks with each other to represent the system. The different libraries are:

1. Values – Used for mathematical calculations, data access or statistical collections. Contains blocks such as Math, Read, Write and Tanks.
2. Items – Models discrete event processes. A sample of item blocks are; Queue, Activity, Batch and Item. And item can contain multiply attributes.
3. Rates – Models discrete rate processes. Tank, Valve, Bias and History are a couple of existing blocks.
4. Plotters – Used to graphically illustrate changes over time. It contains Bar Charts, Histogram and several different Plot types.
5. Animation 2D-3D – Used to animate the state of the model. Example of blocks are; 3D types, Animation and Proof Animate.
6. Utilities – Used for model interfaces, debugging and information. Contains blocks such as Buttons, Record message, Link Alert and Feedback.

In the figure below is an example of a simple ExtendSim model representing a carwash.
The first block is a Create block which creates Items randomly or by schedule. The next block is a Queue which will store the items created and queue them up in a desirable order. Since this is a car wash a common order would in this case be first come – first serve. The next block is an activity block. Activity blocks are used to change the status of the Item and do so during a preset time, example hours or days. The last green block is an Exit block. This block is just here to make sure the Item created at the start leaves the model accordingly. The last block is a Plotter which will in this case plot the number of Items that has exit the model as blue and the number of cars in queue as red.

In the next figure to the right the previous queue has been replaced with a priority queue. In order to give the Item its priority a Set block along with a Random Number block is used. In this case the Random Number block is set to give number one priority with a 10% chance, number two with a 40% chance and number three with a 50% chance. Item with lower priority number will in this scenario be picked first from the queue.

ExtendSim is a great tool for modeling and simulating events and flows of either material or information in a supply chain. It can be used to simulate simple and discrete events such as the car wash along with extremely complicated events with a lot of echelons influencing at different stages and uncertainty. It can be used to simulate the whole supply chain on a high level or zoomed in focusing on one single echelon and its activities. One of the greatest opportunities with using simulation is to investigate how a change in the supply chain will affect its overall performance. Even the slightest change may change the dynamics of the supply chain drastically.

2.4.8 Reducing safety stock

If the organization have an excellent inventory policy reducing the safety stock will have a negative impact on the organizations responsiveness. Reducing the safety stock will increase the possibility to run out of stock and hence create backlogs. Chopra (2013) have however identified several ways to reduce the safety inventory without hurting the availability of the items and the responsiveness. What Chopra (2013) have done is looking at alternative inventory policies and inventory management approaches which will lower the deviation and volatility. Down below is a selection of propositions that is relevant for our case.

1. **Specialization** - Many supply chains offers a wide range of products to customers. When inventory is carried at multiple locations, an important decision a company face is whether all products offered
by the supply chain should be stored at all locations. For example, a product that is clearly not sold in a specific geographic region should not be carried in inventory at that warehouse.

2. **Aggregation** - Aggregating the products to one central warehouse rather than several might reduce the safety inventory of one product significantly. It is better to carry these products at central warehouse rather than each warehouse store it individually. If aggregation would only reduce the required safety inventory by a small amount, it may be beneficial to store this product at each warehouse respectively to reduce response time and transportation cost.

3. **Product substitution** - This refers to the phenomenon when one product can satisfy the demand for another. Substitution can occur in two different scenarios; Manufacturer-driven substitution and Customer-driven substitution. The earlier one occurs when the supplier makes the decision to substitute the requested product with another product with higher-value then the requested due to stock out of the original product. For example, a computer manufacturer changes the hard drive from 1 terabyte to 2 terabytes because the smaller one was out of stock. The later one occurs the same way as above except that the customer makes the decision of substitution. For example, the customer requested a product of one specific brand, but decides to purchase a similar product from another brand due to the requested product being out of stock. The advantages with product substitution are the reduced overall inventory due to aggregate inventory, which results in a reduced safety inventory. However, not all supply chains have the ability to utilize substitution. The reason behind this can either be that a substitute product does not exist or the substitute is to expensive compared to the requested product. A good utilization of customer-driven substitution is important within the retail industry. It should be exploited by placing substitute products near each other. Online retailer may also suggest substitutions if the requested products are out of stock.

4. **Postponement** - Postponement is possible when the supply chain has the ability to delay the product differentiation or customization further down the supply chain, closer to the end customer. The advantages with this strategy is that several products can be configured using the same parts. A classic example of this is coloring. By moving the coloring of the product further down only one type of product needs to be made and then painted at a later stage. A graphical representation of a supply chain with postponement and one without postponement implemented can be found in the figure below. With postponement, a supply chain achieves the same results as when aggregating products, the deviation and uncertainty will be reduced and therefore also reducing the required safety inventory.

5. **Component commonality** - The use of common components in a wide range of the offered products is an effective way to reduce uncertainty by exploiting aggregation, hence reduce component inventories. The component demand is more predictable then the demand of each individual product if it’s used in more than one. In order to make this possible, company’s usually need to configure the design of the component to be more flexible and suit all needs. As a result, the production cost associated with the component usually increases with increasing commonality. The manager therefore needs to consider the tradeoff between increased production costs with the reduced inventory when deciding the appropriate level of commonality for the components.
2.4.9 Forecasting of customer demand

Forecasting of the demand is an important process in calculation of the safety stock. The most commonly adaption is that demand is having a normal distribution (Nenes, et al., 2010; Liu, 2013). Although this is not always the actual behavior of the demand, it is therefore important to understand different behaviors of the demand. **Erratic Demand** have highly variable demand size, **Intermittent** (sporadic, irregular) demand have many periods with zero demand and **Lumpy** (irregular) demand is both erratic and intermittent (Nenes, et al., 2010). **Slow moving** items have intermittent demand with an order size of one or very few products.

Forecasting is a prerequisite to the inventory control, and is an important part of the safety stock calculation, as the demand is varying. In some cases, the probability of being out of stock only depends on the forecasting error. Today the forecasting can be done within the ERP system. Although it is important to understand the effect of the forecasting and in particular what it might cause to our result. The forecasting error is the primary determinant of the safety stock component of inventory investment (Gardner, 1990). Different forecasting methods gives different results in different environment, but the major issue, is to decide the pay-off between delayed delivery and increased inventory costs. This payoff is depending on the company, e.g. there cannot be any stock outs in a hospital where they need their equipment instantly. On the other hand, a seller of newspapers cannot hold a high inventory as all the newspapers will be excess stock the next day. In the ERP-systems today the forecasting can be done by different methods, and the result can have a variation of 5.88 percentage points between the most and least efficient (Catt, et al., 2008).

Herein the forecasting techniques will not be optimized, nevertheless it is an important factor as the demand and the standard deviation of the demand is included in the safety stock calculation. However, its adoption to the safety stock calculations can be part of investigation, as several studies states the demand has seldom a normal or poisson distribution (Dolgui & Pashkevich, 2008; Nenes, et al., 2010; Kumar, et al., 2013). There can be different approaches to better adopt the forecasting to the calculations. One common approach is to include the forecasting error. As the error increases when the horizon increases longer lead times will affect the forecasting error (Karmarkar & Lele, 1989). Generally a safety stock is held during the replenishment lead time, but as it may vary as well.
as the forecasting error, the safety stock will increase (Karmarkar & Lele, 1989). Demand variability will increase while moving up in the supply chain, commonly known as the bullwhip effect, the most important factors for that effect is the demand forecasting and replenishment lead times (Chen & et.al, 2000). Although according to the central limit theorem every distribution can be approximated to a normal distribution with a great numbers of data points. As the number of data points increases it will be better approximated to the normal distribution (Ziegel & Rice, 1995). If the numbers of data points are low, the central limit theorem will not work wherefore another distribution is needed. Which means that for items with lumpy, erratic and intermittent demand will have an inaccurate safety stock calculation.

Keeping an inventory of slow moving items is common in spare parts inventory systems since stock-outs may have undesirable consequences (Dolgui & Pashkevich, 2008). For slow moving items the major problem is the zero consumption over a long period of time which makes it difficult, if not impossible, to forecast. For these items, the normal forecasting techniques are inappropriate. For slow moving items the straightforward approach is instead to calculate the probability of a demand (Dolgui & Pashkevich, 2008).

2.4.10 Safety Stock with Sales lead times

There has been some older research on finding models for particular cases as well as more recent. As the markets are changing, companies search different strategies to gain competitive advantage, where quick response time can be a sustainable source to that (Yang & Geunes, 2004). A reduction in sales lead time will have an impact on the operational performance including the safety stock level (Yang & Geunes, 2004). Sales lead times are the perceived lead times by the customer, and can influence the demand as the customer wants to reduce that time. Yang and Geunes (2007) tries to optimize the positioning of a supplier when it comes to offered lead times and price. Offered sales lead times, will affect both cycle stock and safety stock costs.

\[
SS = k\sigma \cdot \sqrt{L^P - L^S} - \mu(p, L) \tag{2.17}
\]

Where:
- \(L^P\) = Procurement lead time
- \(L^S\) = Sales lead times
- \(\mu\) = Demand function depending on price and lead time

This is only one part of his result, as their main point is to optimize the positioning between sales lead times and procurement lead time for the optimal revenue. This makes that the demand function is not applicable in our case as the sales lead times are fixed. They are suggesting two different solutions in order to optimize this situation, either a pure make to stock policy or a policy where the offered sales lead time will be set the same as the replenishment lead time. Wong and Eyers (2011) criticizes their work to not have a system point of view, they are treating each variable independently why the practical usage will be limited. However, it differs a bit as the replenishment lead times cannot be affected (Chen & et.al, 2000).
2.4.11 Alternative Safety Stock Calculation

Schmidt et al (2012) also takes undershoot of the demand into account. This solves the problem when the stock level has fallen below the reorder point immediately before an order is triggered.

\[
SS = SF(SL) \cdot \sqrt{Var(U)} + LP \cdot \sigma_D^2
\]  
(2.18)

Furthermore, Schmidt et al (2012) are coming up with another formula for calculating the safety stock levels. In this method the safety factor is adaptable as it is only during the replenishment cycle the delivery capability cannot be fulfilled. If a mean delivery capability is desired between the arrivals of two orders, a value smaller than the required delivery capability is sufficient during the critical replenishment phase. Herein they are also having the lead time as a variable, wherefore they are including the standard deviation of the lead time as one parameter in the calculation.

\[
SS = SF(1 - \frac{(1-SL)-Q}{LP \cdot D}) \cdot \sqrt{LP \cdot \sigma_D^2 + D \cdot \sigma_L^2} \quad \forall \ Q > LP \cdot D
\]  
(2.19)

Another approach to the problem with the safety stock calculation is by using a dynamic safety stock calculation. Most of the models are based on statistical parameters, which mean that they are only taking historical data into account. When the historical data is not accurate for the upcoming period, these calculations becomes wrong, wherefore a dynamic approach can be used instead. Becker et al (Becker, et al., 2013) are reviewing several different safety stock models to compare which one to use for which situation to finally come up with their own dynamic model. Dynamic models contain more parameters and requires as the name indicates a more frequent reviewing to have accurate numbers. This is though not always possible in a system with multiple items, as it will be too time consuming (Nenes, et al., 2010). Also Schmidt et al (2012) shows that a dynamic model is not the best in all cases.

2.4.12 Multiple Items

Most of the recent researches in the subject consist of a single product with a single stage (Kumar, et al., 2013). Although most of the companies today are having multiple items, sometimes thousands, which requires another approach for the inventory control. The inventory control system has to be easy to use and yet effective to handle the amount of SKU. With multiple items the demand between the products might differ a lot although the control policy will be the same.

A lot of large companies have an incredible high amount of SKU:s. In a deeper look at those SKU:s it can be seen that a lot of them are very seldom sold. (Nenes, et al., 2010). For example 37.3% of the 145 million SKU:s that the UK Royal Airforce (RAF) kept in stock in 200 had fewer than 10 transaction in a period of 6 years (Dolgui & Pashkevich, 2008). Exceptionally large sporadic demand distorts the demand picture. It is addressable to use the same inventory policy for all items to reduce the complexity, they find out for the company specific case a periodic review policy (T,S) is preferable.

In order to evaluate a system of multiple SKU:s it is according to Nenes et al (2009), necessary to compute the following characteristics, Expected on hand stock, expected shortage per cycle and fill rate (percentage of demand satisfied immediately from available stock). The standard assumption is
that all backorders are filled after procurement is not always the real time case (Nenes, et al., 2010). If the demand is intermittent the backlog might not be possible to fill. Also the order handling time, might cause further delay in the backlog.

Nenes et.al (2009) suggests a decision support system, consisting of the following steps:

1. **Data input**
   - For every SKU, the program should read the code number, fill rate, Lead time, review period and historical demand excluding planned orders.

2. **Check for sufficiency of data demand**
   - If the data is not sufficient according to the set rules the SKU will be kept out of classification.

3. **Demand analysis**
   - A goodness-of-fit to determine the distribution.

4. **Search for spurious demand data**
   - The purpose of this step is to check for any demand outliers, most possible planned orders that has not been removed yet.

5. **Computation of base stock and other characteristics**
   - Except the base stock, this step can also compute other characteristics of interest, most likely, mean demand, variance, proportion of time units with non-zero demand and average stock on-hand.

6. **Final step: Output**

This decision support system is running along with the ERP system at a Greece company, and are provided with the demand data which is update every 6 months and then it gives back the base stock.
3 Current State at Bosch

This chapter aims to describe the current situation at the manufacturing facility at Bosch Rexroth in Mellansel and provide a more in-depth description of the current problem. The information herein is based on continuous interviews with employees at the logistics department. The information provided herein is gathered from the interviews with the employees at the logistics department.

3.1 Product portfolio

Bosch Rexroth is a producer of hydraulic motors and the corresponding drive units. The hydraulic motors have a very high precision inside which makes them more efficient and gives them a longer life cycle than the competitors. Although this gives them a higher production cost and requires a higher sales price which is not always easy to obtain. Along with the previous mentioned products Bosch Rexroth is also a supplier of spare parts used in their products. During the year 2015 the sales of the spare parts corresponded to approximately 7% of the total number of sold articles. Hence the majority of the sales are related to the motors and driving unit which can also be derived from their core competence. Bosch Rexroth core competence lies within the products rather than service or maintenance of the machines.

3.2 Business model

Bosch Rexroth wants to be a system supplier, which means that they want to sell the whole package with motor and drive units. This means that they can map the information in the system to better develop their products and services. Their services are including delivery of spare parts, which are stocked in the factory in Mellansel and offer several support kits that is compatible with their products.

Former years they have mainly focused on keeping high sales volumes, but due to macroeconomic reasons this strategy has changed during the last years. Today the focus is mainly on increasing the profit margin and their competitiveness rather than increasing the sales or revenue. One way of doing that is to outperform their logistics activities. This can be done both by minimizing the inventory level or the lead time towards the customer. One part of increasing the customer experience was to introduce sales lead times on the majority of the articles. Sales lead times can be explained as a promise to the customer that the product will be shipped from the factory before the sales lead times due date. Sales lead times exist on both the finished products, such as motors, and the single items which do not require any processing. A more detailed description will be provided later. To avoid stop in manufacturing it is necessary to maintain a high availability of raw material required in the process. However, since some of the items or raw material can be sold as spare parts as well it is essential that these policies will have no negative impact on the service level of orders associated with spare parts. Although as their supply chain consist of a wide range of different suppliers of raw materials and components, the purchase lead times varies between items. These items can later be used in the same motor or have a high correlation in sales. As indicated this can be problematic when the whole supply chain does not have a common strategy (Chopra, 2013).

Bosch Rexroth have accomplished a good collaboration with the majority of their suppliers and managed to reach high delivery reliability. Even so, during the interviews it was stated that 25% of the purchase orders are delivered late. Purchasing of raw material and parts are done from different sub-supplier, although, the same parts are only purchased from a single supplier. The products are then assembled or stored before they are delivered to customers.
Due to the complexity and number of possible configuration in a motor and drive system Bosch Rexroth founds it not feasible to withhold a stock of finished goods or larger assemblies. The strategy used in Bosch Rexroth is assemble-to-order for motors and drive units and sales-from-stock for spare parts. Although the strategies and the logistic processes are different they are still stored in the same physical stock. As there are two different strategies the safety stock calculation has to be applicable in both cases. It has to maintain a high availability for raw materials in the production while having a high availability for the spare parts for sales. Herein there can though be a difference in sales lead times, and where it is mostly consumed. Although to maintain a high production rate even during periods with low demand, some sub-assemblies can be stored in smaller supermarkets. The supermarket mostly only contains a few number sub-assemblies used for products with a high turnover. Therefore, the majority of the stock is composed of raw material or items. Even though Busch Rexroth is carrying a very low inventory of sub-assemblies and no inventory of finished goods they consistently strive to meet customers increasing demands on shorter lead times and faster deliveries. Bosch Rexroth solution for this dilemma has been the implementation of the previous mentioned sales lead time. Spare parts have been given a direct lead time while the more complex products have been assigned a delivery model. The delivery models refer to the maximum number of weeks it takes to get the product ready for shipment, starting from raw material. The preparation includes processing, assembly, testing, painting and shipping of different kinds. Items on the other hand are products that can shipped straight of the shelf after packaging and thus not have a delivery model. A typical example of an item is a spare part or an accessory, such as a special brake that can be attached after the final assembly of the motor. The delivery model and the sales lead time are decided depending on market demands and might therefore have a weak connection to the complexity of the product or the manufacturing lead time.

3.3 Inventory Management

As the company strategy is to maintain service on their offered systems during the whole lifecycle Bosch Rexroth stores both spare parts and parts for manufacturing in their inventory. The full list of items contains more than 60 000 items. However, some of these products are no longer active but still remains in the list. When removing both stopped items and BOM articles, the list can be reduced to roughly 8000 items. Looking at the historical orders 49.5 % of these items has not had any consumption during the last 12 months. After such reduction 4277 items remains on the list. In addition to this the supplying system consists of several suppliers and several customers, which gives a system like Nenes et.al (2009).

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>1</td>
<td>50%</td>
<td>90%</td>
</tr>
<tr>
<td>2</td>
<td>90%</td>
<td>95%</td>
</tr>
<tr>
<td>3</td>
<td>90%</td>
<td>95%</td>
</tr>
</tbody>
</table>

Table 1: Bosch Rexroth ABC-classification matrix

<table>
<thead>
<tr>
<th>Class</th>
<th>Picks/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1-6</td>
</tr>
<tr>
<td>1</td>
<td>7-12</td>
</tr>
<tr>
<td>2</td>
<td>13-24</td>
</tr>
<tr>
<td>3</td>
<td>25-</td>
</tr>
</tbody>
</table>

Table 2: Previous ABC distribution

Due to the high number of items Bosch is using an ABC-classification for their inventory control. In addition to the ABC-classification they added a ranking system based on how many times that item is included in an order every year. The quantity of the order is not taken in to account when ranking the
items. Items that are picked less than six times per year are given the lowest rank, which will in this case be cero. Items that are picked more times than six but less than thirteen are classified as one. Class two have the boundaries less than 25 but greater than twelve and class three contains all items that are picked more than 24 times per year. This provides a serviceability matrix where each rank receives a service level. The service level matrix can be found in table 1 and the picking class distribution can be found in table 2. The classification is updated every fourth week, and only items sold within the last 12 months are included. The boundaries of each class may change depending on the spread of the items. A while back the classes had slightly lower boundaries but were changed because too large a fraction of the items was given the higher classes. A graphical illustration of today’s picking classification compared to the previous can be found in table 3.

With these changes the amount of items given a CSL of 0.5 was increased by 23 percentage units. While both 0.9 and 0.95 were reduced by 5 and 18 respectively. The percentage along with the amount of items can also be found in the table below.

*Table 3: CSL before and after the distribution reconfiguration of the classification.*

<table>
<thead>
<tr>
<th>CSL</th>
<th>Before (units)</th>
<th>After (units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>1911 (37 %)</td>
<td>2960 (60 %)</td>
</tr>
<tr>
<td>0.9</td>
<td>931 (18 %)</td>
<td>663 (13 %)</td>
</tr>
<tr>
<td>0.95</td>
<td>2376 (45 %)</td>
<td>1362 (27 %)</td>
</tr>
</tbody>
</table>

The inventory can be separate into four different categories; no-movers, raw material, products in work and finished goods. No-movers are products not sold at all the last two years, yet the inventory may still include some of these products. From time to time some of those products are sold with a discount to remove them from the inventory. Raw material, is the main focus of this report, raw material consists of both, slow movers and fast-movers, where slow movers are products that requires more than 90 days to turnover. Herein is items sold as spare parts, used in the production or a combination of these. In extreme cases spare parts can be sold with as long as ten years apart. Due to a policy to close contracts for items with no demand record over the last three years, these items will take more resources to replenish. If an item is not stored at Bosch Rexroth and have a long purchase lead time the customer sometimes chooses to discharge their order which naturally leads to missed sales opportunity.

Even though the reconfiguration of the ABC classes reduced the number of items classified with a higher service level, Bosch Rexroth have not yet experienced an increase in stock outs, although according to the interviewees it’s relatively close from time to time. Looking at the KPI they still achieve an average fill rate above 95 %. According to Bosch Rexroth they rarely experience stop in the production due to stock outs. The problem they have identified with the current ABC classification is that it can according to them rank items with high purchase price to high which consequently leads to increased inventory costs. Furthermore, items with a high purchase price might also be purchased in higher quantities. The reason behind these is usually connected to contracts offering a discount. However, when this is noticed from the employees they sometimes contact the supplier to discuss the possibility of ordering in lower quantities. On some products the quantity is given by physical constraints such as amount of items that fits in a box or pallet. For this reason, these items can be more difficult to order in lower quantities. Reversibly items that are
contracted with a low quantity can sometimes be purchased weekly accumulated if the employee recognize a planned order in the near future.

In practice, Bosch Rexroth only have one warehouse where they store the majority of their items. In the ERP system however there are nine different warehouses (001, 002, 003, Quar, Spare, Cons, Estock, Astock and QQ). For that reason, some items can in practice be stored at one location but in the ERP system have nine different inventory characteristics. Each inventory therefore has its own safety stock, inventory level and transaction. This consequently leads to an increased safety inventory due to increased volatility. Furthermore, giving an item several inventory levels has historically lead to an increased inventory due to the contracted minimum order quantities. The reason to the overstocking is that the ERP-system suggests purchase orders for each warehouse individually which results in that each warehouse might be replenished with the minimum order quantity although it had a low historical demand.

3.4 Sales lead times

The company recently introduced sales lead times, which as described earlier can be described as promise to the customer that the order will be shipped within the sales lead time. Within the ERP system each article has a registered replenishment and a sales lead time. Items can also have been assigned a delivery model. Only items which are included in a product with a delivery model are given one. A delivery model is closely related to the sales lead time but instead of days refers to within the maximum number of weeks the product will be shipped from Bosch Rexroth warehouse. The replenishment and sales lead times for each item are contracted with suppliers and therefore fixed parameters. These parameters can however be updated a few times per year if new contracts have been made. The sales lead times are set by the sales department adjusted to the market of the concerned item, while the replenishment lead time is negotiated by the purchasing department with the suppliers. Furthermore, it is said that the order handling time is five days, which means that from the delivery arrives it takes at least five days before it can be delivered to a customer and the production lead time for the finished products are three days. However, according to the interviewees those promised sales lead times are not always fulfilled, which leads to delayed delivery’s and in some cases annull ed orders. Occasionally large orders for spare parts are incoming which are emptying the whole stock of raw material for the production. Furthermore, this may lead to penalty costs and additional administ rational costs. Occasionally for special important customers the orders are shipped by airplane if the delivery date is not fulfilled. As the customers as well as the orders can be of different importance the cost for a delayed delivery is very hard to estimate. Nenes et.al (2009) has also discussed this dilemma in their work. Furthermore, the sales lead times also leads to a higher inventory than necessary.

If the raw material used in the production would run out of stock it requires a lot of extra administrative costs. Firstly, they will try to get the required material faster than normal by negotiation with the supplier. If the supplier is unable to ship the supply within the desired date, new suppliers will in turn be considered who are able to do so. Also if necessary also the raw material can be transported by airplane. Even though all these options imply an increased purchase cost it might still be a feasible solution since stop in production can be much more damaging.

Even after the introduction of sales lead time, the customer constantly asks for shorter lead times. If they desire to fulfill these demands, it will lead to additional administ rational costs.
3.5 Logistic situation

The inbound logistic situation is fairly complex where an item has multiple purposes, in some cases Bosch Rexroth can be seen as a logistic warehouse, every item has to pass by the factory even though it could avoid delays by going immediately from supplier to customer, as the placement of the factory is a bit limited geographically. A strategy like these is also known as dropped shipment. The flow of product can be seen as in figure 10. One item can be used in the production or be sold as a spare part. However, if products sold as spare parts and used for manufacturing are separated the supply chain could be seen as a direct supply chain which is the supply chain relationships with the least complexity Mentzer et al. (2001). In both cases the item has a sales lead time. If it is used in the production the production lead time has to be considered as well. For finished components the production lead time is three days. Before starting the production, all raw materials should be available. Occasionally customers make large orders for spare parts, which in worse case will empty the storage, wherefore there is no raw material available for the production. To avoid that situation, they have considered having separate inventories for items sold as spare part and used for production, but the decision was that this option would not be feasible due to increased total inventory.

![Value Stream Mapping](image)

FIGURE 11: VALUE STREAM MAPPING

The purchase department is establishing contracts and is negotiated with the suppliers for price and order quantities. Normally if a product is not sold for three years the contract expires.

The forecasting is done with a top down analysis, which means that the management starts on factory level and estimates the yearly total sales of the factory. This is done by reviewing the sales from former years and take the current macro situation into account along with other statements that would impact the yearly sales. From that, estimations of how many of each motor and control unit they will sell are made, these estimations include some already planned orders and some orders which are expected. From this they are going down further in the product tree in order to evaluate the required bill of material (BOM) for each item. The forecast on the last items in the tree is then
used to estimate how many of that item they will need on a weekly basis for their production. In addition to that some items, is also sold as spare parts, going immediately from the inventory to the customer as in figure 10. Also there are some items sold only as spare parts. The forecasting for the sales of spare parts is not based on historical demand but rather based on their own experience and impressions. For those items which are both part of a BOM and sold as spare parts, there is no separation taking out the expected demand from the ERP-system. The forecasting is mainly done for items with a higher frequency of sell rates, otherwise the forecasting would get too inaccurate. If a motor is forecasted all the items in the BOM are forecasted as well, occasionally that change so another motor is forecasted instead. However, even though the forecast is change on the motors, the forecasting of the BOM’s remains the same since it does not have a link in the ERP-system.

Due to obvious reasons, the further in to the future the forecasting is made, the less accurate it becomes. When the forecasting horizon comes closer, the system converts forecasted orders with the incoming real orders. Although this is not always performing well, this means that when the due date arrives there might still be some forecasted demands not yet converted into real demand. The result of this is a higher level of inventory then actually necessary since the purchase is triggered by a forecast rather than an actual demand. Today there is no follow up on the forecasting, which has led to unawareness whether the forecast is accurate or not. Since the forecasted demands turns into real demand, it is taken out of the system and there is no way to trace it afterwards.

3.6 Stock Policy

The current stock policy has three main parts that can trigger a purchase order. These parts are; forecasting, demand driven and safety stock. All items will have demand as a triggering point. The items can therefore with an inventory perspective be split up in the following types.

Type 1: Safety stock and forecasting.

Type 2: Safety stock no forecasting.

Type 3: No safety stock, no forecasting.

Type 4: Forecasting no safety stock.

For a Type 1 item, purchase orders will be triggered according to the forecasted demand as well as if the stock level drops below the safety stock. It can therefore be considered as a \((r, T, Q)\) system. At every period \(T\) the inventory levels will be reviewed, if the inventory level at this point is below the stock level \(r\), a purchase order with quantity \(Q\) will be placed. This order could be placed even if there has been no actual demand in the previous periods due to the forecast. A purchase can also be made if the demand is considered to not follow the forecasted demand pattern. These demands are seen as unexpected and will thus not influence the initial forecast. Demands of such type can for example be of an unusual quantity.

For the Type 2 items the safety stock solely working as a reorder point. The policy for those items can therefore be considered to be of \((r, Q)\). Commonly the reorder point is the sum of the safety stock and the mean demand during the replenishment lead time, wherefore the safety stock calculation in this case might be too low since the expected demand is not considered.

Type 3 items should be those who are sold very seldom and therefore do not have a safety stock. A purchase for these items is only done when the demand exceeds the stock level, meaning the on hand inventory is not sufficient to satisfy the demand. To still maintain a high service level for these items the sales lead time is supposed to be longer than the replenishment lead time. If this is the
case, the item can be replenished when the order is made and still be shipped in time. Although as the purchasing quantities are significantly bigger than the demand, there can in practice be several units remaining in the stock for a long time.

**Type 4** is rarely occurring and consists of special items. Special items are connected to demand which was classified as unique. An example of a unique demand is typically a larger project consisting of many different products which in some cases needs special treatments. Therefore, those items will not be considered herein.

For items sold both as spare parts and used in the production there is no difference in the forecasting, neither in the on hand inventory. Occasionally some items are requested in larger quantities when bought as spare parts. When this occurs the inventory might be emptied resulting in a stop in the production. For these items the demand pattern is considered to be very lumpy.

### 3.7 Safety stock

The current safety stock calculation is done according to the basic SERV1 definition. The safety stock calculation is done within the ERP-system, but the calculations are seen as recommendations rather than strict. Formerly it was updated once a year, but was recently changed and is now updated once every quarter. The calculations are done according to equation 3.1.

\[
SS = k\sigma \sqrt{E(Lt)}
\]  

(3.1)

The variable k is calculated after the given abbreviation list which based on the given CSL. The standard deviation of the demand is estimated by the ERP system based on historical demand on a monthly basis. The lead time is the replenishment lead time given in the contract from their suppliers.

### 3.8 Problems

The general thought by the employees at the logistics department, is that for items sold frequently there is normally no problem with the safety stock other than that it seems too high. For items which are sold more seldom and has a distinct difference between sales and replenishment lead time, there tends to be problematic to fulfill the sales lead times. Also articles sold seldom and therefore missing contract with a supplier.

Employees have pointed out that there are no existing routines for removing items that are no longer considered as active. These leads to increased complexity and in some cases increased inventory cost hence these items are stored even though they are not available for purchasing. Furthermore, there are several other factors which increase the complexity of the inventory policies, this factors are:

- A large variety of different items, almost 10’000.
- Two different distribution channels – spare parts and production.
- Variety in demand pattern for different type of items, in particular for spare parts safety stock calculation based on assumption of normal distribution.
- Availability of data, no forecasting follow up, standard deviation for total demand, service level for total demand and value.

The standard deviation of the demand given by Microsoft AX Dynamics is in some cases unrealistic and theoretically impossible. The most extreme case is an item with an historical consumption of 17 per year and a monthly standard deviation of 1981. Which gives a RSD above the theoretical
maximum which as stated earlier. Recalling back the highest possible RSD assuming a monthly data gathering is 1907.8784 %. In our case the highest RSD is given if the yearly consumption is from a single month while the other months have zero consumption. In this case the RSD is given by:

\[ RSD = \frac{1981}{12 \times 17} = 139835.2941 \% \]

This is almost a factor 100 larger than the theoretically possible. Clearly the ERP system is not providing accurate and correct numbers for all items. After a closer look in this matter, observations where made that this phenomenon only occurred on items that had either changed shelf or where modified in a recent inventory review. In both cases, these changes where influencing the calculations of the standard deviation, even though it was not connected to an actual demand.
4 Formulation of the safety stock model

In this section the possible root problems will firstly be described. Later in the section alternative methods and possible solutions to the problem will be presented.

4.1 Possible root problems

By analyzing the data from the ERP-system along with the information gathered from the employees at the logistics department, several potential root problems have been identified, alone or mixed up. To provide a better have a view the problem can be broken down resulting in the following figure.

The safety factor \( k \) has its origin from the service level, wherefore this variable will be subject of research. Furthermore, the standard deviation assumes a normal distribution, which may not always be the case. Alternative distribution functions might be of interest. As the sales lead times is recently introduced and cannot always be fulfilled, there is obviously a problem that they are not integrated in the current safety stock calculation. Isolating each one of these variables, possible reasons to the inaccuracy can be found. Lastly the lead time is an important factor in particular because the recent introduction of sales lead time. The current formula is based on the assumption that the customer demands needs to be fulfilled by items taken immediately from the shelf. Due to the implementation of sales lead time this is necessarily not the case. As a result of the implementation of sales lead time, it is assumed that the customer accepts a delayed delivery which implies that the demand in this case does not need to be fulfilled straight from the shelf. Easily, the sales lead times can be integrated according to the formula by Yang and Geunes (2007).

\[
SS = k\sigma \sqrt{L_p - L_s - \mu(p, L)} \quad (4.1)
\]

Since the sales lead time is not a variable itself as Yang and Geunes (2007) treat it, the additional demand function \( \mu \) will not be relevant in our case. In most practical cases organizations require some extra time between received and delivered goods. This can for example include the need for registration of the goods received in to the ERP system before making it available for delivery. Another possibility is that the organization receives their goods at the afternoon while orders are shipped at the morning (Lindmark, 2016). Therefore, a parameter considering the order handling time \((OH)\) will be added to the equation. At Bosch Rexroth this time is considered to be five days and makes the real purchase lead time longer. The updated formula will therefore be given equation 4.2.

\[
SS = k\sigma \cdot \sqrt{L_p + OH - L_s} \quad (4.2)
\]
As the sales lead times will always be positive, the differential inside the root sign will always be smaller than the former case, not considering the OH. This will lead to a lower safety stock and a general decrease in the inventory levels. This general decrease will therefore reduce the tied up capital which will emancipate capital for an increase for items with a lower fill rate or reduction in cost. Although, by reducing the safety inventory on these identified items might result in a negative impact on the average fill rate. Thus reduce the possibility of meeting the customer demanded sales lead times, wherefore some particular items need to have an increased stock level to achieve a higher fill rate, both average and individually.

Another suggestion is to use the formula from Schmidt et al (2012).

\[ SS = SF(1 - \frac{(1 - SL)Q}{LP \cdot D}) \cdot \sqrt{LP \cdot \sigma_D^2 + D \cdot \sigma_L^2} \quad \forall \ Q > LP \cdot D \] (2.19)

Taking the sales lead times and the order handling time into account, and seeing the problem as lead time being a fixed parameter, it gives us the following equation.

\[ SS = SF \left( 1 - \frac{(1 - SL)Q}{(LP + OH - L^2) \cdot D} \right) \cdot \alpha \cdot \sqrt{LP + OH - L^2} \quad \forall \ Q > (LP + OH - L^2) \cdot D \] (4.3)

Although the criteria \( Q > LP \cdot D \) will lead to a further decrease in the stock levels. As the quota \( \frac{Q}{(LP + OH - L^2) \cdot D} \) always will be bigger than one, resulting in the differential \( 1 - \frac{(1 - SL)Q}{(LP + OH - L^2) \cdot D} \) which will always result in a reduced CSL, wherefore the safety stock will also be reduced. However, this formula takes into account the problem when the purchasing quantities are larger than the demand during the lead time. When calculating the costs with this formula, it could be found out that it just marginally reduced the costs, wherefore it was decided to not be further researched.

However, none of these formulas considers the scenario when items are used for multiple purposes and therefore might consist of two different sales lead times. Looking at the total safety stock as a sum of two separate inventories rather than one it leads to the following modification:

\[ SS_{tot} = SS_{prod} + SS_{spare} \]

\[ SS_{tot} = k \alpha \cdot f_{prod} \cdot \left( \sqrt{LP + OH + PL - L^s_{prod}} + f_{spare} \cdot \sqrt{LP + OH - L^s_{spare}} \right) \] (4.4)

Which theoretical gives two inventories, splitting the inventory in too two separate inventories will lead to an increased total safety stock due to the increased deviation in demand. By splitting up the inventory the advantages with an aggregate inventory suggested by Miranda and Garrido (2004). For that reason, the aggregated standard deviation will be used instead. Although these might in some cases be unfeasible and mathematically incorrect on specific items it will however not have a large influence when looking at the whole picture.

To solve the previous mentioned problem with the standard deviation, the lead time can instead be seen as a time varying parameter. This enables to have the aggregate effect while still considering the possibility of differences in lead time. Combining these theories with the equation suggested by Schmidt et al (2012) gives the following equation:

\[ SS = k \cdot \sqrt{L^A \cdot \sigma_D^2 + D_L \cdot \sigma_L^2} \] (4.5)

Where,

\[ L^A = f_{prod} \cdot (LP - L^s_{prod} + PL) + f_{spare} \cdot (LP - L^s_{spare}) + OH \] (4.6)

\( \sigma_D \) is calculated by looking at the historical demand and \( \sigma_L \) is calculated as suggested in equation 4.7
\[ \sigma_L = \sqrt{\sum (X_i - \mu)^2 * P(X_i)} \] (4.7)

When looking at the dilemma from a system point of view articles are treated differently in the ordering system although the safety stock for each item is calculated the same way. For articles with forecast the safety stock is used as the theory suggests, meaning items of this type is replenished when the level drops below the ROP which consist of both the expected demand and the safety stock. For articles without forecast however, the safety stock is working as a ROP itself which means that the safety stock would theoretically be too to be able to achieve the desired fill rate. This dilemma might not have been identified today since the sales lead times are not implemented and are therefore already carrying a higher safety stock then required. This phenomenon is also known as the Japanese lake. For items without both forecast and safety stock, there is no inventory, even if there is a consumption during the lead time. Therefore, it can be seen that the inventory system is supposed to have the characteristics shown in the table. The safety stock herein can be calculated with different formulas, and \( \mu \) is the average demand during lead time. Although problematic with this one is that it may increase the inventory even though they today in general are satisfied with their responsiveness.

**Table 4: Forecast types matrix.**

<table>
<thead>
<tr>
<th>Safety Stock</th>
<th>Forecast</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>SS</td>
<td>( \mu + SS )</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>0</td>
<td>( \mu )</td>
<td></td>
</tr>
</tbody>
</table>

The ABC-classification is today including the number of picks and volume value, to complement that, articles with extra-long lead times are added manually. To solve this dilemma another classification method could be used which includes all these parameters. The new method is to use the formula suggested by Zhang et.al (2001). The advantage of this method is that it prioritizes items with lower uncertainty, hence longer lead time increase the variation in demand and increase the risk of running out of stock no matter the initial service level. If the cost is given by a percentage of the price equation 2.1 can be rewritten as followed:

\[ \frac{D}{(h \cdot p)^2 \cdot L} \] (4.8)

In the current service level distribution, the numbers of pick are combined with the standard ABC classification based on the value and volume ratio. An item receives one pick if it is included in a production order or if it is sold as a spare part in a sales order. Therefore, when included in a production order the item will only be counted once regardless of the quantity. The reason behind this is that some items have a high average order quantity. By doing so, they avoid unfeasible safety stock quantities. For example, keeping a safety stock of 30 items when the average order quantity is above 100 is not considered feasible since the safety stock is unable to satisfy an increased demand. In this scenario a safety stock would not make any difference since the order of 100 items can still not be delivered. During the model testing phase both the replenishment lead time and the net lead time was used. However, when using the replenishment lead time as \( L \) the results was caused for different sets of data. For that reason, the net replenishment lead time is used, which provided a
result who followed the same pattern. The service level will affect the safety factor $k$ which is based on the given service level of the item. Teunter et.al (2010) suggests increasing the industrial standard of three classes to instead use six categories. This will allow a more accurate distribution of items among the groups as well as reducing the gap between the classes. However, by increasing the number of classes the complexity of the model is increased as well. The initial 4x3 matrix will with six categories instead become a 4x6 matrix which is an increase of 100%. The number of different configuration is however increased tremendously. The rule of thumb is that the cell to the next in line, to either right or down, should be higher or equal to the original cell. An example of how a 4x6 matrix could look like can be found in the table below.

*Table 5: CSL matrix with six ABC classes and four pick classes.*

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
<td>0.6</td>
<td>0.7</td>
<td>0.7</td>
<td>0.8</td>
<td>0.9</td>
</tr>
<tr>
<td>2</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
<td>0.9</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>3</td>
<td>0.7</td>
<td>0.8</td>
<td>0.9</td>
<td>0.9</td>
<td>0.95</td>
<td>0.95</td>
</tr>
</tbody>
</table>

As stated by several authors (Nenes et.al, Gardner et.al, Eppen et.al) the forecasting is generally a root cause to the inventory problems. Herein, the goal is not to evaluate the performance of the forecasting, although it can be evaluating whether the forecasting method is appropriate for the item according to the decision support system suggested by Nenes et.al (2009). Were planned orders should be taken out of the historical demand. They also suggest doing a distribution fitting. Although central limit theorem proves that over time, distributions can be assumed to have an approximate normal distribution (Rice, 1995). Although the approximation will be more accurate with increased sample size (Rice, 1995). However, since items with a low transaction history will be given a low or no safety stock according to the CSL matrix, the problem with the distribution fitting will be a minor problem in this case. Some methods also suggest including the forecasting error in the safety stock calculation, unfortunately this is not possible in our case as there is no available data of the historical forecasts. The last alternative is practical issues, which is not subject of research for this paper. Although findings show that the calculation of the standard deviation in the ERP-system are not accurate in some cases, mostly due to reappraisal after stock-taking.

### 4.2 Alternative solutions

Based upon the possible root problems, some possible solutions have been found that could solve these problems. For each solution there will be at least one proposition that could potentially solve one or several of these problems. Later on, the best proposition for each alternative solution will be set together in order to maximize the profit.

**Solution 1 – Safety stock calculation**

The safety stock calculation has become inaccurate after the introduction of sales lead time and has resulted in a higher safety inventory then necessary on some items. This is the main topic of the
master thesis but as we have seen that there might be additional problems connected to the formula, we have this as our primary solution and believe that a change of safety stock calculation will reduce the inventory. We have two different propositions to solve this problem.

**Proposition 1.1**

Including the sales lead times in the current safety stock calculation with variations in lead time will reduce the safety stock level without compromising the performance.

\[
SS = k \cdot \sqrt{L^A \cdot \sigma_D^2 + D_L \cdot \sigma_L^2} \quad (4.5)
\]

\[
L^A = f_{prod} \cdot (L^P - L_{prod}^s + PL) + f_{spare} \cdot (L^P - L_{spare}^s) + OH \quad (4.6)
\]

**Proposition 1.2**

Including the sales lead times in the current safety stock calculation with two theoretical inventories should reduce the safety stock level without compromising the performance.

\[
SS_{tot} = k \sigma \cdot \left( f_{prod} \cdot \sqrt{L^P + OH + PL - L_{prod}^s} + f_{spare} \cdot \sqrt{L^P + OH - L_{spare}^s} \right) \quad (4.4)
\]

Those two propositions will only decrease the stock level on items with a relative long sales lead time. Wherefore the problem with not fulfilling the demand on certain items will remain.

**Solution 2 - Classification**

The current ABC-classification with the belonging service level matrix is made for older circumstances and does not take the lead times into account.

**Proposition 2.1**

Using the new ABC-criteria below will decrease the inventory for products with a long net lead time. By doing so, items with lower net lead time will be given higher service levels while products with longer net lead time will be given lower.

\[
\frac{D}{(h \cdot p)^2 \cdot L} \quad (4.8)
\]

**Proposition 2.2**

Increase the number of ABC-classes from three to six to reduce the gap between each class and provide a more accurate classification.

**Solution 3 – Stock policy**

Their current stock policy is not fully considered to the circumstances.

**Proposition 3.1**

Adding a reorder point for the items without a forecast will increase the average fill rate.

In order to evaluate the performance for the propositions each of them will be simulated using the ExtendSim 9 software as well as calculate the safety stock cost. In the next section the results from the simulation and the costs will be presented.
5 Results

In this section the results of the report will be presented, including the simulation and the costs.

5.1 Simulation of Bosch inventory system

To see the performance of the inventory system and how a change of safety stock levels would affect the fill rate and cycle service levels, several simulation runs were conducted. In order to evaluate the performance, the simulation model was built to create customer demand approximated to the real demand and evaluate the on hand inventory at the end of each day. Commonly used blocks in the model were Constants, Queues, Set and Math. A full overview of the model can be found in appendix 1. The simulation was done on all 4277 items that was active at the time the data was gathered on March 21 2016. Each item had its unique attributes based on real data from the case study. The safety stock calculation in the simulation was based on sales history between 21 of March 2014 and 20 of March 2015 while the demand variables were calculated based on a daily demand for the upcoming year, 21 of March 2015 to 20 of March 2016. The system was seen as a single echelon where each item only had one supplier and one customer.

Depending on the demand frequency of an item, different statistical distributions were used. According to the central limit theorem a population greater or equal to 30 can be approximated following a normal distribution pattern. Therefore, these items were assumed to have a normal distribution demand while items with a demand less than 30 times per year were assumed to have a demand following a poisson distribution. Since the normal distribution may provide negative demand, all negative numbers where changed to zero instead. The poisson function was firstly used to generate a demand. The mean of the poisson function were equal to the likelihood that a demand occurs each day (number of days with sales divided by the 365, the number of days in a year). The position of the poisson was zero. The quantity of the generated demand was then later generated triangularly with a minimum, maximum and most likely quantity. To simulate the sales lead time, the net lead time was used as the replenishment lead time. Since an item can have different net lead times if it is sold as a spare part or used in the manufacturing, the replenishment lead time was simulated after a normal distribution function with an average lead time and a standard deviation. These where both calculated according to the earlier mentioned equations. That said, all items with a net lead time of zero or lower would be replenished the same day as the replenishment order were placed. The replenishment order quantity for each item where set as the standard order quantity given by the ERP-system. The starting inventory for each policy was assumed to be half the replenishment order quantity plus the reorder point. That means that the simulation will start halfway through the replenishment cycle.

The KPI:s was as mentioned before measured at the end of each day. By doing so the demand could first be generated and then allow the replenishment orders to arrive allowing the generated demand to be satisfied before measuring the inventory levels. The measured KPI:s were; order fill rate, product fill rate and cycle service level. The order fill rate measured the percentage of orders that could be delivered the same day they were generated, while the product fill rate would also consider the quantity of products that could not be delivered, since a generated demand can have a quantity greater than one. For example; if a demand of ten products is generated, but at the end of the day there are only five products available on hand, it will count as one towards the order fill rate but as five products for the product fill rate. It will also count towards the cycle service level, if there has not already been a stock out during the same replenishment cycle. The KPI:s were measured during a 5 year period for all the 4277 items that would in theory represent a simulation of one year five times
since all of the inputs where based on yearly numbers, only difference would be the starting inventory for each year. By simulating five years the influence of randomness could be eliminated that could have occurred if only one year were used.

Eight simulations where made with different settings. These settings were set based upon the different propositions to evaluate these would influence the performance of the inventory policy. The company is in practice using a forecasting for some of their items, but since there is not consistence whether all expected demand is forecasted or not herein a reorder point was used instead which is based upon historical demand. The reorder point will therefore have the same effect as a forecasting with continuous expected demand has. Although this is complicated since their demand varies a lot from year to year. Due to the uncertainty in demand they have an under forecasting, and are covering it up with a safety stock. This situation is difficult to simulate, since they have some market input and already planned orders when they make their forecast. However, since not all items are forecasted in reality, these items where neither given a reorder point in the simulation. An overview of the KPI results from the simulation can be found in the table below.

Table 6: ExtendSim KPI results

<table>
<thead>
<tr>
<th>Stock policy</th>
<th>Order fill rate</th>
<th>Product fill rate</th>
<th>Weighted Product fill rate</th>
<th>CSL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current safety stock level</td>
<td>57,6%</td>
<td>62,0%</td>
<td>87,7%</td>
<td>25,3%</td>
</tr>
<tr>
<td>1.1</td>
<td>57,6%</td>
<td>62,0%</td>
<td>87,2%</td>
<td>25,2%</td>
</tr>
<tr>
<td>1.2</td>
<td>56,9%</td>
<td>61,2%</td>
<td>86,6%</td>
<td>22,0%</td>
</tr>
<tr>
<td>Current SS + new ABC</td>
<td>57,7%</td>
<td>62,2%</td>
<td>88,3%</td>
<td>24,6%</td>
</tr>
<tr>
<td>Current SS + 6 classes</td>
<td>57,4%</td>
<td>61,9%</td>
<td>88,6%</td>
<td>24,3%</td>
</tr>
<tr>
<td>1.2 + 6 classes</td>
<td>57,1%</td>
<td>61,4%</td>
<td>87,4%</td>
<td>22,3%</td>
</tr>
<tr>
<td>NO SS</td>
<td>55,6%</td>
<td>59,9%</td>
<td>82,9%</td>
<td>18,7%</td>
</tr>
</tbody>
</table>

However, these attributes are of no use unless it is compared to the safety stock levels along with its costs. Therefore, the number of items that are carrying a safety stock, the total quantity along with the total cost for each proposition is displayed in table below. On top of that, column four displays the safety stock as fraction of the total inventory cost. The total inventory cost in this case is the safety inventory plus the turnover inventory, which is on average half the order size. The turnover inventory will be the same for all propositions since the order quantity do not change. Thus to reduce the turnover inventory the order quantities needs to be reduced. Today some of the items have an order quantity significantly bigger than their yearly consumptions due to old contracts with the suppliers. For those items with quantities like these will get a good fill rate though one batch will cover all the demand during a year.

Table 7: Attributes for the simulation

<table>
<thead>
<tr>
<th>Stock policy</th>
<th>Items with SS</th>
<th>Number of SKU</th>
<th>SS Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current safety stock level</td>
<td>1 418</td>
<td>19 613</td>
<td>100%</td>
</tr>
<tr>
<td>1.1</td>
<td>1 184</td>
<td>19 390</td>
<td>95,9%</td>
</tr>
<tr>
<td>1.2</td>
<td>1 090</td>
<td>17 603</td>
<td>59,3%</td>
</tr>
<tr>
<td>Current SS + new ABC</td>
<td>1 342</td>
<td>22 086</td>
<td>68,2%</td>
</tr>
<tr>
<td>Current SS + 6 classes</td>
<td>1 332</td>
<td>21 788</td>
<td>99,9%</td>
</tr>
<tr>
<td>1.2 + 6 classes</td>
<td>1 308</td>
<td>21 600</td>
<td>126,3%</td>
</tr>
<tr>
<td>NO SS</td>
<td>1 170</td>
<td>19 935</td>
<td>64,3%</td>
</tr>
</tbody>
</table>
From the different tables it can be seen proposition 1.1 performs not as well as the other and 1.2 even a bit worse. Although this is not a big difference and 1.2 is clearly cheaper with both the simulated data and the current data. If this proposition is added to the new ABC-criterion with 6 classes, it does decrease the safety stock value with more than 50% with the current data without affecting the performance.

Table 8: Comparison between the models with current data

<table>
<thead>
<tr>
<th></th>
<th>Old safety inventory</th>
<th>New calculations</th>
<th>New calculations + new abc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of items</td>
<td>2 030</td>
<td>1 692</td>
<td>1 985</td>
</tr>
<tr>
<td>SKU:s</td>
<td>163 612</td>
<td>119 252</td>
<td>131 585</td>
</tr>
<tr>
<td>Turnover inventory (units)</td>
<td>418 932</td>
<td>418 932</td>
<td>418 932</td>
</tr>
<tr>
<td>Safety inventory fraction (units)</td>
<td>35,5%</td>
<td>23,2%</td>
<td>18,9%</td>
</tr>
<tr>
<td>Reduction of safety inventory (SEK)</td>
<td>0,0%</td>
<td>-45,1%</td>
<td>-57,5%</td>
</tr>
</tbody>
</table>

5.2 Randomized items

Until now only items with attributes gathered from the case study have been used. To see whether the cost saving was specific for this case or generalizable different numbers had to be used. In order to explore this, several safety stock calculations were made where all the characteristics each items were randomized. Since the existing ABC classification no longer could be used these safety stock costs were not applicable in this test. Instead all costs were compared to the current safety stock calculations but instead with the new ABC classification. The number of items was changed between the tests as well, different item quantities were used, such as 100, 1000, 4277 and 10000 unique items. However, for each set of items the results were fairly the same. A summary of the results can be found in the table below.

Table 9: Safety stock calculations based on randomized item characteristics

<table>
<thead>
<tr>
<th>Number of items</th>
<th>SS AX New ABC</th>
<th>SS 1.2 New ABC</th>
<th>SS AX 6 classes</th>
<th>SS 1.2 6 classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0,0%</td>
<td>-52,5%</td>
<td>-25,2%</td>
<td>-61,1%</td>
</tr>
<tr>
<td>1000</td>
<td>0,0%</td>
<td>-56,2%</td>
<td>-23,8%</td>
<td>-61,9%</td>
</tr>
<tr>
<td>4277</td>
<td>0,0%</td>
<td>-54,9%</td>
<td>-24,5%</td>
<td>-61,0%</td>
</tr>
<tr>
<td>10000</td>
<td>0,0%</td>
<td>-57,0%</td>
<td>-25,2%</td>
<td>-62,3%</td>
</tr>
</tbody>
</table>

The displayed value is a mean from five different simulations with a standard deviation slightly above one percent for each of the sets. The results indicate that there could be cost saving of 60% by implementing proposition 1.2 with a new ABC-criterion with 6 classes compared to the original safety stock calculation with a new ABC-criterion with 3 classes.

5.3 Excel Bolt-on

In order to make this inventory policy feasible it must be easy to use. Today the safety stock calculations are made in the ERP-system with only a few clicks. Therefore, to make this suggestion more feasible it has to be something similar, if it is too complicated it will not be updated frequently enough and therefore not reach its full potential. As suggested by many authors an Excel-Bolton is a good alternative due to its user friendliness. Therefore, an Excel Bolton program with a few macros was made to make the implementation more smoothly and to make sure it is used as intended. Even
though (Farasyn, et al., 2008) suggested to not go for too many macros the Excel Bolt-on in this case had a one button execute. Below is a description of how it worked.

The Excel Bolt-on was built to be as user friendly as possible, to make sure the excel Bolt-on would be maintained and updated and would be compatible with the existing calculations in effort and time as well. The user first had to fill two pages with data gathered from the ERP-system. The first page would include all necessary information about the item such as: price, sales volume, purchase lead time, sales lead time etc. The second page would include the transaction history for all items. This page would later be used to calculate the proportion of sales that is related to production and spare parts respectively, as well as counting the number of transaction that will be used in the new ABC classification. When this pages were filled with data the user hit the execute button and the magic began. The results were presented on an individual page where all the item along with the suggested inventory would be displayed. In order to make the results traceable and to make it so that an interested user could follow the steps, each of them was showed on a separate page. This was also done to avoid the dilemma pointed out by Farasyn et al. (2008) that the results would feel like magic and therefore not trustworthy. A full list of Macros used can be found in appendix 3 to 6.

5.4 Reorder point

As mentioned the forecast are based on a top down forecast with a continuous demand, which will have the same effect as a reorder point. However not all items today have a forecast. The items sold most frequently have a forecast, while items sold less do not have a forecast. Although to have a forecast or reorder point on those items might be difficult though the demand pattern is harder to forecast. From the data set it can be seen that several thousands of items sold one year had no sales the year after. This makes it non-cost effective to add a reorder point to the other items. The safety stock is therefore used to protect against those fluctuations in the most cost efficient way, while the other items has to have a more frequent review to achieve a higher fill rate.
6 Discussion

This chapter includes the general discussion regarding the project, discussions about the results of the simulation and the credibility of these results.

6.1 General discussion

Already from day one this project where influenced from supervisors and employees with an idea to lower the inventory costs without putting too much effort on how the reliability would be affected. For that reason, other potential methods left untouched even though they could have been of interest if the cost did not weight that much more than the reliability.

6.2 Method of choice

In order to gather the necessary information a case study was carried out. By doing so we were able to acquire the depth in the understanding required to solve the problem. This knowledge depth would not have been obtainable with other methods. However, if another method then a case study would have been used, where several different companies where asked the findings might have been different. Although this method would not have provided the depth but would instead have provided more width than the previous mentioned method. However, we believe that the depth was crucial to understand the true cause of the problem and that other methods might have missed this and found a sub-optimal solution. Also, it is unclear how many others are using sales lead times.

6.3 Simulation

The simulation was used to verify the alternative solutions. To gain a better view of the performance of the propositions the simulation was conducted with three possible outcomes, a major decrease in total demand, similar total demand and major increase in total demand. From that we summarized the results in a table and compared with the related safety stock costs. As the simulation are generating numbers based on a standard deviation and mean value it leads to a variation between the simulation runs. Wherefore a minor difference cannot be statistically proved. The calculations were based on data from 2014, and as there is a big difference in items demanded between these years there is a lot of products not being in the simulation. However, these are products that did not have a consumption during 2015 wherefore the performance would not have been different, it would just be the cost that would have changed. Therefore, both the costs for 2014 and 2015 are included to see how much the safety stock would have cost today.

Our first alternative solution was that a different safety stock calculation would decrease the safety stock cost without affecting the performance. We had two different propositions for this solution, 1.1 and 1.2. There can be seen that the current safety stock calculation has a minor higher performance than proposition 1.1 and 1.2. Proposition 1.1 also performs better than 1.2. Although it can be seen that the costs are significantly lower, especially for proposition 1.2. Proposition 1.1 has not a big difference in cost for year 2014 although it is clearly cheaper for 2015. However, with proposition 1.2 the safety stock would decrease with around 40% but risk to not perform as well as the current safety stock calculations, although as there is this major difference in cost the generally service level can be increased to increase the performance. We have in summarization taken the adjusted cost per percentage into account, which is the cost for each percent above the performance for an inventory system without a safety stock in the unchanged case. Where proposition 1.2 is clearly the cheapest, even though the performance is not linear, the savings are so much bigger that there still would be possible to achieve the same service levels with a lower cost. 1.2 is cheaper than 1.1
though it does not include the variation in lead time, this is probably why it has a bit lower performance as well, though it on does items has a lower safety inventory compared to proposition 1.1.

Table 10: Weighted fill rate with changes in demand and related costs for different safety stock calculations.

<table>
<thead>
<tr>
<th></th>
<th>AX</th>
<th>1.1</th>
<th>1.2</th>
<th>NO SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill rate with 40% decreased demand</td>
<td>98,44%</td>
<td>98,45%</td>
<td>98,34%</td>
<td>97,62%</td>
</tr>
<tr>
<td>Fill rate with unchanged demand</td>
<td>87,72%</td>
<td>87,19%</td>
<td>86,60%</td>
<td>82,89%</td>
</tr>
<tr>
<td>Fill rate with 40% increased demand</td>
<td>69,23%</td>
<td>69,56%</td>
<td>69,36%</td>
<td>65,75%</td>
</tr>
<tr>
<td>Reduction in percentage (SEK)</td>
<td>0,00%</td>
<td>-4,07%</td>
<td>-43,07%</td>
<td>-100,00%</td>
</tr>
<tr>
<td>Adjusted cost per percentage fill rate (SEK)</td>
<td>100,00%</td>
<td>107,70%</td>
<td>74,10%</td>
<td>Invalid</td>
</tr>
<tr>
<td>Reduction in percentage (SEK)</td>
<td>0,00%</td>
<td>-18,12%</td>
<td>-36,63%</td>
<td>-100,00%</td>
</tr>
<tr>
<td>Adjusted cost per percentage fill rate (SEK)</td>
<td>100,00%</td>
<td>92,00%</td>
<td>82,40%</td>
<td>Invalid</td>
</tr>
</tbody>
</table>

For our second alternative solution, that a different ABC-classification would decrease the costs, without affecting the performance. This analysis was done in the same manner were we had two propositions 2.1 with a new ABC-criterion and 2.2 a new ABC-criterion with 6 classes. Herein the same safety stock calculations were used on all propositions, only the classification changed. For those three alternatives there is no significant difference in performance, thus it is major difference in costs between the propositions and the current classification. It differs a bit between the years, although it is in all the cases clearly cheaper to change the classification. A new ABC-criterion with 6 classes seems to be the best though it is cheaper for the current year. As the new criterion included lead times as the major difference, the long lead times have had a great impact on the value kept in stock.

Table 11: Weighted fill rate with changes in demand and related costs for different ABC-classifications.

<table>
<thead>
<tr>
<th></th>
<th>AX</th>
<th>New ABC 3 classes</th>
<th>New ABC 6 classes</th>
<th>NO SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill rate with 40% decreased demand</td>
<td>98,44%</td>
<td>98,39%</td>
<td>98,37%</td>
<td>97,62%</td>
</tr>
<tr>
<td>Fill rate with unchanged demand</td>
<td>87,72%</td>
<td>88,32%</td>
<td>88,59%</td>
<td>82,89%</td>
</tr>
<tr>
<td>Fill rate with 40% increased demand</td>
<td>69,23%</td>
<td>70,43%</td>
<td>70,64%</td>
<td>65,75%</td>
</tr>
<tr>
<td>Reduction in percentage (SEK)</td>
<td>0,00%</td>
<td>-61,16%</td>
<td>-61,19%</td>
<td>-100,00%</td>
</tr>
<tr>
<td>Adjusted cost per percentage fill rate (SEK)</td>
<td>100,00%</td>
<td>34,60%</td>
<td>32,90%</td>
<td>Invalid</td>
</tr>
<tr>
<td>Reduction in percentage (SEK)</td>
<td>0,00%</td>
<td>-22,28%</td>
<td>-39,89%</td>
<td>-100,00%</td>
</tr>
<tr>
<td>Adjusted cost per percentage fill rate (SEK)</td>
<td>100,00%</td>
<td>69,10%</td>
<td>50,90%</td>
<td>Invalid</td>
</tr>
</tbody>
</table>

To have a complete evaluation of the performance we made a combination of proposition 1.2 and 2.2 which were the best performing in their cases. We can though see that we can decrease the safety stock costs with more than 50% without affecting the performance. With our theoretical findings this number should be 60% for the general case. The performance for 6 classes compared to 3 classes is better, wherefore there must have been items in the boundary between class A and class B having a great impact on the performance.
Table 12: Weighted fill rate with changes in demand and related costs for the new model.

<table>
<thead>
<tr>
<th></th>
<th>AX</th>
<th>1.2 New ABC 6 classes</th>
<th>NO SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill rate with 40% decreased demand</td>
<td>98,44%</td>
<td>98,36%</td>
<td>97,62%</td>
</tr>
<tr>
<td>Fill rate with unchanged demand</td>
<td>87,72%</td>
<td>87,77%</td>
<td>82,89%</td>
</tr>
<tr>
<td>Fill rate with 40% increased demand</td>
<td>69,23%</td>
<td>70,02%</td>
<td>65,75%</td>
</tr>
<tr>
<td>Reduction in percentage (SEK)</td>
<td>0,00%</td>
<td>-68,45%</td>
<td>-100,00%</td>
</tr>
<tr>
<td>Adjusted cost per percentage fill rate (SEK)</td>
<td>100,00%</td>
<td>31,20%</td>
<td>Invalid</td>
</tr>
<tr>
<td>Reduction in percentage (SEK)</td>
<td>0,00%</td>
<td>-50,67%</td>
<td>-100,00%</td>
</tr>
<tr>
<td>Adjusted cost per percentage fill rate (SEK)</td>
<td>100,00%</td>
<td>48,90%</td>
<td>Invalid</td>
</tr>
</tbody>
</table>

If the safety inventory would be updated today (2016-03-21), the cost saving with our proposed model would be 54%. Although the inventory consists of two parts, the turnover inventory and the safety inventory. The turnover inventory is the orders sizes dived in two which should be the average turnover inventory of a longer time period. This part of the inventory is though the same for all the proposed models as it was not a part of our investigation. We can though see from that see that with our new model the safety inventory’s fraction of the total inventory will decrease a lot. To further reduce the inventory, the turnover inventory should be investigated.

6.4 Possible Weaknesses

- Simulation of forecast – The forecast done at the company is done with a top down approach. It is partly based on already planned orders and based on historical demand and macroeconomic inputs. Since the sales of motors and drive units is project based, it is hard to forecast which projects they will win in the future. This situation and uncertainty is hard to get into the simulation. Thus this is a problem occurring for all the tried models in the simulation wherefores it should not affect the internal comparison.
- Supplier reliability – This is something we wanted to include in our model, although we could not find the accurate data for this. Lowering the safety stock levels, the sensibility for supplier reliability will become higher.
- Short time period – Since it is hard to trace back all the data many years, we only used data from 2014 until now. In this time period there has been a decrease in sales. Although we simulated an increase in sales as well to avoid that problem. However, a longer time period of data would have been preferable to increase the reliability.
- Surrounding world analysis – We were in contact with Alexander Würst the supply chain manager of Bosch Rexroth’s headquarters in Lohr, Germany. He was not aware of any safety stock model within the corporate group developed to solve the same problem as ours. Although there is a weakness that we have not been in contact with any other company facing the same problem as we are. This will also decrease the generalizability.

We conducted the simulation run with data from 2014 on an outcome of the dataset of 2015. Due to the reduction in sales from 2014 to 2015 the safety stock levels where based on higher numbers then the simulated demand. We wanted to investigate a broader spectrum of cases, so the simulated cases were:

- Decrease of sales compared to the year before.
- Unchanged level of sales compared to the year before.
- Increase of sales compared to the year before.
The changes in sales were similar to the real change of 36% in total sales. The different cases were simulated to see if anyone of the models performed differently in the different cases. There could be a possibility that the items with a lower safety stock level would perform worse if the demand increased. However, we could with our simulation show that all the models performed equally between each other except in the first case. In the second case, with an unchanged demand, model 1.1 and 1.2 performed worse than the others, otherwise there was no significant difference in fill rate.

With an increase of the demand compared to the first simulation setup, all the models performed poorly. Therefore, with a drastic increase of demand it is not the safety stock that has the greatest impact when it comes to performance but rather the forecasting. The safety stock should be updated more frequently if the demand changes drastically, as suggested by Li et.al (2006), which the last case simulated. On the other hand, updating it too frequently may not be feasible due to the long replenishment cycles and time consuming.

### 6.5 Alignment with company strategy

It is important that the proposed model will be applicable with the company’s strategy. With a make-to-order strategy our model will propose which products that should carry a higher inventory that will depend on the delivery model group. With the 2 week project a motor needs to have all its components at least arriving the same day as the order arrives. For motors with longer promised sales lead times, the components could be arriving later than the order arrives or in some cases be kept out of stock and be commanded when the order arrives. Still with all this, the company strategy will be achieved in the same way as before. If the sales lead times want to be further decreased to better satisfy the customer demand, there is no longer possible to achieve by adjusting the raw material safety stock levels, then there needs to be an increased productivity or inventories carrying sub-assemblies. This will however increase the total inventory cost. If Bosch Rexroth wants to maintain the same inventory cost, there will need to be a higher degree of modularization.

For the spare parts, there is a sales-from-stock strategy, where customers request their products to be shipped immediately. During our interviews we found out that the customers are frequently trying to negotiating in order to receive shorter lead time. Although if the company has chosen to implement sales lead times, this model will limit this possibility for the customer as there will be less units kept in stock. This is a pay-off which has to be done by the company, between responsiveness and costs which as described earlier is a difficult decision to make. The safety stock levels can be adjusted if necessary by adjusting the sales lead times, if the market so requires.

Sales lead times is a way to communicate the responsiveness to the customers. With almost 10 000 active items, it is impossible to have all in stock in still offer a competitive price. Also the sales lead times might change the customer behavior and force them to do more continuous purchasing.

### 6.6 Implementation

It is essential that the implementation of a new inventory policy is made properly. That said the implementation should be made in such way that the new policy is implemented carefully prepared and that the results of the implementation is followed up closely. As Chopra (2013) suggests the easiest way to achieve success is to implement in smaller incremental steps rather than all at once in order to evaluate the results of the new policy and hence have the possibility to make small adjustments if necessary. Therefore, the implementation should be done in three stages where the
next stage will not start before the previous stage is well implemented and reviewed. A stage gate model of the suggested implementation strategy can be found in the figure below.

By following this implementation model, it will be easier to identify the cause of any potential problem and furthermore find a long term solution rather than just contemporary solution which might have been the case if they were all implemented at once. To gain quick access to the results and have an easy implementation process, it would be smart to have the evaluation before each new update of the safety stock, which according to Li et al (2006) should be done between 3-6 months. An example of an adjustment can be to change the distribution between the classes in the ABC classification. If the implementation of the new ABC classification or the extension to six classes performs more poorly than the existing inventory policy, the fraction of items given the higher classes can be increased.

If the new model still does not outperform the old one after several iterations this most likely means that this model does not align with your business strategy and is therefore not performing to its full potential. If this is the case it does not necessarily mean that anyone of the following stages will generate good results.

We therefore suggest to skip that phase and move on to the next. If for example the second phase is not providing the expected results and is for some reason performing more poorly than the existing inventory policy, we suggest that you move forward to phase three meaning implement six classes on your current ABC classification rather than the suggested since it is proven that extending the ABC classification from three to six classes will allow more possible configurations and therefore possibly generate an increased responsiveness at a lower cost.

Important to notice is that phase three can be adjusted more than once due to its large number of possible configurations. For that reason, phase three could be carried out for a much longer period than the previous phases. However, when the gains from each adjustment falls lower than the costs for making them, phase three along with the full implementation should be marked as finished.
6.7 Updating interval

The simulation was based on the data from both 2014 and 2015. The set safety stock levels and ROP was based upon order history from 21 March 2014 to 20 of March 2015 while the simulated demand was based upon the order history from the following year, meaning 21 of March 2015 to 20 of March 2016. This was done in order to simulate a real based case while still gathering enough data. Preferable would have been to gather demand data for only four or six months to better mirror the reality. But due to some of the assumptions made it was more feasible to simulate the demand from a full year. The relative results between the safety stock levels simulated will still be valid. The difference is that the actual achieved fill rate will in practice be higher than the achieved fill rate through the simulation, if a higher update frequency is used.

Today the ABC-classification is updated every third month and the safety stock should be done accordingly to that. Our simulation was done on a yearly basis, which means that the performance was as the updating was done once a year. Theory suggests that the update frequency should be more often. Preferably after three to six months unless some major changes have been done or if the behavior of any variable has changed (Li, et al., 2006). This could for example be a change of demand pattern or a change in either sales or purchase lead time. If it is done more often it will take a lot of time, and it will be hard to achieve the suggested stock levels. On the other hand, if it is updated with a lower frequency, the demand and standard deviation might change a lot and the calculations is based on inadequate data.
6.8 Reorder Point and Forecasting

Bosch Rexroth are today not using a reorder point, instead they are using forecasting with safety stock to cover up for the inaccuracy of the forecasting. We were investigating the possibility to add a reorder point to the safety stock to increase the fill rate for items without forecasting. Although with our simulation we found out that it would increase the average fill rate, but it would drastically increase the costs. As the company in general is satisfied with their current fill rate, the cost of adding a reorder point would not increase the company’s competitive advantages.

As they have a big shift in demand and large external factors influencing their demand their forecasting is very complicated. It is very hard to forecast their future demand by looking at the historical sales. This is also the case for the reorder point which is based on the historical demand, and will just risk to become inaccurate due to the big shifts in demand. For a lot of spare parts, it is complicated to forecast the demand as the customer normally orders the spare parts in big batches. However, for a lot of customers they are their only distribution channel which gives them a strong bargaining power.

6.9 Reliability, Validity and generalizability

To verify our solutions, we conducted a simulation on real data. We separated the data to be like a real situation with the calculations based on data one year back and the simulation data on one year forward, this will increase the reliability. Since the data is not unique but rather based upon the reality with a mean and standardization the result is not limited to this specific set-up which makes it more valid. To furthermore experiment whether the results was dependent on the product portfolio multiply runs where made with randomized data. The results from these experiments followed the same pattern already pointed out which shows that the results are both valid and reliable.

Some might argue that the generalizability of this study is limited since much of the results is based on a case study carried out at one single company. However, since the gathered data was taken from the ERP-system which had no bias it could be generalized to other similar companies as well. Furthermore, when analyzing the cost saving with randomized items the results remained the same as mentioned earlier. Even when changing the volume in sales the reliability for the proposition remained the same. For that reason, the results are not limited to this unique case but can be successfully implemented in any enterprise.

6.10 Future research

This problem has a high complexity and there can be a lot of development in order to achieve the best possible model. The approach in this problem has mostly been to reach “the low hanging fruits” and come up with a model suitable for the current company situation. Although there were several parts we did not research due to either the complexity or the lack of reliable data.

Analyzing the current safety stock levels, we found out that some safety stock levels were way too high compared to the relatively low historical demand. After a further research it could be found out that the ERP-system generated a wrong standard deviation in those cases. We have based our calculations on another standard deviation. This standard deviation is taken from the transaction log. With these changes in standard deviation the safety stock value could decreases for all formulas. It is of great importance for the company to look at this to avoid unnecessary stock.
Today there is no following up of the forecasting, the forecasting itself may be possible to improve. Considering the safety stock calculation as they are using a forecasting and not a reorder point, there would be interesting to include the forecasting error in the calculation as suggested by Karmarkar and Lele (1989).

The complexity of the problem can be easily increased and we suggest that the delivery reliability should be included in the calculation as it has a major impact on the safety stock levels. Neither this could be done due to the complexity of getting the correct data. However, they are today mapping which suppliers that has problems with achieving their lead times, and are working on improving the communication with the suppliers. Hopefully this will lead to better on time delivery and therefore a less necessity of including the supplier reliability.

To achieve a higher customer satisfaction and compete on the international market it is not only important to have a high delivery satisfaction. It is also important to try to have the shortest sales lead times possible. To be able to lower the sales lead times the replenishment lead times has to be lowered to not drastically increase the inventory. Wherefore important future research is how the replenishment can be lowered and also how lowering the sales lead times will affect the costs. Also a further investigation should be done about the correlation between articles, articles often sold together should preferably have the same sales lead times.

Today some customer, orders large quantities compared to the average sales quantity and expect it to be sold immediately or in minimum the sales lead times. To always be able to cover up for those quantities the

In this report we have suggested a method to keep a more efficient level of safety stock which is based upon fill rate on a single item. However, in reality items are seldom sold alone but are a part of a larger order of items. This is especially true when used in the manufacturing. For that reason, it might be interesting to investigate which items that are often sold together or part of the same manufacturing assembly. If these items are given different service levels, then the item with the lowest service level will be the dominating one and the higher one will never be achieved. Therefore, looking at items with correlation and giving them the same service level could be more efficient. The difficult task however is to decide which service level that would be appropriate for these items. Especially when one item has a strong correlation with multiply items. To make it applicable in practice companies should be given a rule of thumb or a framework based on the previous mentioned aspects.

In this paper we have limited our self to look at the supplier as a single echelon. The next step would be to evaluate how these changes would influence the remaining echelons in the supply chain. Furthermore, evaluate the possibility to improve the safety stock levels by also considering the other echelons inventory level. However, since the required data to test such an implementation was not available today these hypotheses could not be validated.

As pointed out earlier, the deviation in replenishment lead time can be devastating and negatively influence the delivery performance for a supplier. In order to resist this dilemma one can choose to carry some extra safety stock if such an event should occur. However, in this paper we have not investigated the outcome of such a policy. The main reason behind this is the absence of necessary historical record of such events. The next step would therefore be to test performance of the suggested calculation method to see how it would perform when this dilemma is considered in the calculations.
7 Conclusion

We have in this work shown that Bosch Rexroth and companies in a similar situation can use proposition 1.2, as shown in equation 4.4, together with a new ABC-criterion with 6 classes to make their safety stock more cost efficient. By doing so, they can reduce their costs today with 57.5% without compromising the performance, which was verified with simulation. Our randomized number generation proves that there are cost savings of 60% with the proposed model. The introduction of sales lead times, gives a longer respite period for the company wherefore they can hold a lower safety inventory. We can therefore conclude that there is of great importance that the company is either shortening their lead times or including the sales lead times in the calculation as it has a major impact on the safety stock levels. Although for the concerned company the safety inventory is today 53% of the total inventory cost, the rest is connected the turnover inventory. With our model the safety inventory as a fraction of the total inventory cost drops to 34%. To furthermore reduce the total inventory, the turnover inventory has to be reduced, which is mostly connected to the order quantities.

\[ SS_{tot} = k\sigma \cdot (f_{prod} \cdot \sqrt{L^P + OH + PL - L^S_{prod}} + f_{spare} \cdot \sqrt{L^P + OH - L^S_{spare}}) \] (4.4)

If the demand would increase significantly, the fill rate will naturally decrease, although in those cases the fill rate decreases for all the alternative models as well as the existing. For those cases there is instead the forecast and order quantities that has the major impact on the performance. On the other hand, if the sales decrease all the models gains increased fill rate and the numbers converge each other. The simulation was done to investigate how these policies would perform compared to the existing. The simulation demonstrated the outcome when the safety stock levels were updates once a year. To further increase the performance, the safety stock calculations should be updated more frequently, preferable after 3-6 months. A reduced safety stock will reduce the possibility for the customers to negotiate about the sales lead times on their order. On the other hand, it will increase the transparency of the company, the offered sales lead times will be more valid for all the customers. If necessary, the reduced safety inventory enables a reduction in the offered sales lead times. With a different ABC-classification some products will change group and be kept out of stock. For some customers this can have an impact but on overall it should not affect the serviceability. With the new ABC-classification, more items will be kept in stock but in lower quantities.

To get the best possible results from the proposed model the implementations should be done in three steps. Step one includes the implementation of the new formula. In the following step the new ABC classification will be implemented along with the previous implemented formula. In the last step the earlier used three classes will be replaced by six classes which provide the possibility for a wider range of configurations along with reducing the gap between the given service levels. Before initiating the following step, the previous step should be reviewed to evaluate if small adjustments are necessary to achieve the desired goals.
8 Bibliography


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List of interviews

- Rose-Mari Edmark, material planner at Bosch Rexroth AB, 2016-04-05
- Ingegerd Själin, material planner at Bosch Rexroth AB, 2016-04-05
- Benedikte Goldman, order administrator at Bosch Rexroth AB, 2016-04-04
- Yvonne Sjöberg, order administrator at Bosch Rexroth AB, 2016-04-06
Sub Create_List_of_Items()
Dim num_rows As Long
Sheets("IP All Items").Select
num_rows = ActiveSheet.UsedRange.Rows.Count
Rows("1:1").AutoFilter

'Removes Items without Rexroth ID, other than items and stopped
ActiveSheet.Range("$A$1:$HG$57957").AutoFilter Field:=2, Criteria1:="<>"
ActiveSheet.Range("$A$1:$HG$57957").AutoFilter Field:=7, Criteria1:="Item"
ActiveSheet.Range("$A$1:$HG$57957").AutoFilter Field:=107, Criteria1:="No"
ActiveSheet.Range("$A$1:$HG$57957").AutoFilter Field:=118, Criteria1:="No"

'Copies the relevant items to a new sheet
Rows("1:1").Select
Range(Selection, Selection.End(xlDown)).Copy Destination:=Sheets("List of Items").Range("A1")

'Sort away the articles not sold the last year

'Clears the input sheet
Sheets("IP All Items").Select
Rows("1:1").AutoFilter
Cells.Select
Selection.ClearContents

End Sub
Sub separate_warehouse()
'
' Create_records_per_WH Macro
'
'Show input sheets
Sheets("Spare").Visible = True
Sheets("001").Visible = True
Sheets("002").Visible = True

'Clean input sheets
Sheets("Spare").Select
Cells.Select
Selection.ClearContents

Sheets("001").Select
Cells.Select
Selection.ClearContents

Sheets("002").Select
Cells.Select
Selection.ClearContents

'Hide Columns
Sheets("IP Safety Stock").Select
Rows("1:1").AutoFilter
Columns("B:B").EntireColumn.Hidden = True
Columns("D:E").EntireColumn.Hidden = True
Columns("G:P").EntireColumn.Hidden = True
Columns("S:U").EntireColumn.Hidden = True
Columns("X:X").EntireColumn.Hidden = True
Columns("AB:AH").EntireColumn.Hidden = True
Columns("AJ:AO").EntireColumn.Hidden = True

'Copy WH Spare data to input sheet
ActiveSheet.Range("$A:$AO").AutoFilter Field:=3, Criteria1:="Spare"
Range("A1").Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlDown)).Select
Selection.Copy
Sheets("Spare").Select
Range("A1").Select
ActiveSheet.Paste
Range("A1").Select

'Copy WH 001 data to input sheet
Sheets("IP Safety Stock").Select
Application.CutCopyMode = False
ActiveSheet.Range("$A:$AG").AutoFilter Field:=3, Criteria1:="1"
Range("A1").Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlDown)).Select
Selection.Copy
Sheets("001").Select
Range("A1").Select
ActiveSheet.Paste

'Copy WH 002 data to input sheet
Sheets("IP Safety Stock").Select
Application.CutCopyMode = False
ActiveSheet.Range("$A:$AO").AutoFilter Field:=3, Criteria1:="2"
Range("A1").Select
Range(Selection, Selection.End(xlToRight)).Select
Range(Selection, Selection.End(xlDown)).Select
Selection.Copy
Sheets("002").Select
Range("A1").Select
ActiveSheet.Paste

'Remove filter
'Sheets("IP Safety Stock").Select
'Rows("1:1").Select
'ActiveSheet.ShowAllData
'Rows("1:1").Select

Sheets("IP Safety Stock").Select
Cells.Select
Selection.ClearContents

Sheets("Spare").Visible = False
Sheets("001").Visible = False
Sheets("002").Visible = False

'Range("B1").Activate
'Selection.AutoFilter
'Range("B1").Select

End Sub
Appendix 4

Sub Create_transactions()

Dim num_rows As Long

'Clear the data sheet
Sheets("Transactions").Select
Cells.Select
Selection.ClearContents
Application.CutCopyMode = False

'Copies the relevant columns
Sheets("IP Transactions").Select
num_rows = ActiveSheet.UsedRange.Rows.Count
Range("E1:E" & num_rows).Copy Destination:=Sheets("Transactions").Range("B1")
Range("L1:L" & num_rows).Copy Destination:=Sheets("Transactions").Range("C1")
Range("H1:H" & num_rows).Copy Destination:=Sheets("Transactions").Range("D1")

'Clear the input sheet
Sheets("IP Transactions").Select
Cells.Select
Selection.ClearContents

End Sub
Appendix 5

Sub Lead_time_Calculations()

Dim num_rows As Long

' Clears the target sheet to avoid any conflict
Sheets("SS-Calculations").Visible = True
Sheets("Transactions").Visible = True

Sheets("SS-Calculations").Select
Cells.Select
Selection.ClearContents
Application.CutCopyMode = False

Sheets("List of Items").Visible = True
Sheets("List of Items").Select
num_rows = ActiveSheet.UsedRange.Rows.Count

' Copies all the relevant columns to the calculation sheet
Range("C1:C" & num_rows).Copy Destination:=Sheets("SS-Calculations").Range("B1")
Range("V1:V" & num_rows).Copy Destination:=Sheets("SS-Calculations").Range("AH1")
Range("CV1:CV" & num_rows).Copy Destination:=Sheets("SS-Calculations").Range("C1")
Range("DA1:DB" & num_rows).Copy Destination:=Sheets("SS-Calculations").Range("D1:E1")
Range("DV1:DV" & num_rows).Copy Destination:=Sheets("SS-Calculations").Range("F1")
Range("FF1:FG" & num_rows).Copy Destination:=Sheets("SS-Calculations").Range("G1:H1")
Range("GC1:GC" & num_rows).Copy Destination:=Sheets("SS-Calculations").Range("I1")
Range("GT1:GU" & num_rows).Copy Destination:=Sheets("SS-Calculations").Range("J1:K1")
Application.CutCopyMode = False

Sheets("SS-Calculations").Select
num_rows = ActiveSheet.UsedRange.Rows.Count
Application.CutCopyMode = False

' Create purchase lead time
Range("L1").Select
ActiveCell.FormulaR1C1 = "Purchase Lead time"
Range("L2").Select
ActiveCell.FormulaR1C1 = "=IF(RC[-7]=""Yes"",RC[-8],RC[-8]/7*5)"
Range("L2").AutoFill Destination:=Range("L2:L" & num_rows)
Range("L1:L" & num_rows).Copy
Range("D1").PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks _
   :=False, Transpose:=False

' Create spare sales lead time
Range("L1").FormulaR1C1 = "Spare Sales Lead Times"
Range("L2").FormulaR1C1 = "=RC[-6]/7*5"
Range("L2").AutoFill Destination:=Range("L2:L" & num_rows)
Range("L1:L" & num_rows).Copy

'Create Price
Range("L1").FormulaR1C1 = "Price"
Range("L2").FormulaR1C1 = "=if(RC[-4]=0,RC[-5],RC[-5]/RC[-4])"
Range("L2").AutoFill Destination:=Range("L2:L" & num_rows)
Range("L1:L" & num_rows).Copy

create production lead time
Range("L1").FormulaR1C1 = "Production Lead Time"
Range("L2").FormulaR1C1 = _
Range("L2").AutoFill Destination:=Range("L2:L" & num_rows)
Range("L1:L" & num_rows).Copy
Range("H1:L" & num_rows).Delete

......

Sheets("SS-Calculations").Select

num_rows = ActiveSheet.UsedRange.Rows.Count
Application.CutCopyMode = False

Range("J1").FormulaR1C1 = "SS-Level"
Range("J2").FormulaR1C1 = _
"="IFERROR(VLOOKUP(RC[-9],"001"!C1:C3,3,FALSE),0)+IFERROR(VLOOKUP(RC[-9],"002"!C1:C3,3,FALSE),0)+IFERROR(VLOOKUP(RC[-9],Spare!C1:C3,3,FALSE),0)
Range("K1").FormulaR1C1 = "Current Stock Value"
Range("K2").FormulaR1C1 = _
"="IFERROR(VLOOKUP(RC[-10],"001"!C1:C4,4,FALSE),0)+IFERROR(VLOOKUP(RC[-10],"002"!C1:C4,4,FALSE),0)+IFERROR(VLOOKUP(RC[-10],Spare!C1:C4,4,FALSE),0)
Range("L1").FormulaR1C1 = "STDEV"
Range("L2").FormulaR1C1 = _
"="SQRT(IFERROR(VLOOKUP(RC[-11],"001"!C1:C7,7,FALSE),0)^2+IFERROR(VLOOKUP(RC[-11],"002"!C1:C7,7,FALSE),0)^2+IFERROR(VLOOKUP(RC[-11],Spare!C1:C7,7,FALSE),0)^2)
Range("M1").FormulaR1C1 = "Service Level"
Range("M2").FormulaR1C1 = _
"="MAX(IFERROR(VLOOKUP(RC[-12],"001"!C1:C11,11,FALSE),0),IFERROR(VLOOKUP(RC[-12],"002"!C1:C11,11,FALSE),0),IFERROR(VLOOKUP(RC[-12],Spare!C1:C11,11,FALSE),0))"
Range("J2:M2").AutoFill Destination:=Range("J2:M" & num_rows)

Range("N1").FormulaR1C1 = "Production orders"
Range("O1").FormulaR1C1 = "Sales Orders"
Range("N2").FormulaR1C1 = 
  
  "=-1*SUMIFS(Transactions!C[-11],Transactions!C[-12],""=""&RC[-13],Transactions!C[-10],""=""Production line"")"

Range("O2").FormulaR1C1 = 
  
  "=-1*SUMIFS(Transactions!C[-12],Transactions!C[-13],""=""&RC[-14],Transactions!C[-11],""=""Sales order"")"

Range("P2").FormulaR1C1 = 
  
  =COUNTIF(Transactions!C[-14],""=""&RC[-15])"

Range("N2:P2").AutoFill Destination:=Range("N2:P" & num_rows)
Range("J1:P" & num_rows).Copy

......

Sheets("SS-calculations").Select
num_rows = ActiveSheet.UsedRange.Rows.Count

Range("Q1").FormulaR1C1 = "Production percentage"
Range("Q2").FormulaR1C1 = 
  
  "=IF(RC[-3]+RC[-2]=0,0,RC[-3]/(RC[-3]+RC[-2]))"

Range("R1").FormulaR1C1 = "Sales Percentage"
Range("R2").FormulaR1C1 = 
  
  "=IF(RC[-3]+RC[-3]=0,0,RC[-3]/(RC[-3]+RC[-4]))"

Range("S1").FormulaR1C1 = "NLT production"
Range("S2").FormulaR1C1 = 
  
  "=IF(RC[-15]+8-RC[-14]<0,0,RC[-15]+8-RC[-14])"

Range("T1").FormulaR1C1 = "NLT sales"
Range("T2").FormulaR1C1 = 
  
  "=IF(RC[-16]+5-RC[-14]<0,0,RC[-16]+5-RC[-14])"

Range("U1").FormulaR1C1 = "Average Lead time"
Range("U2").FormulaR1C1 = 
  
  "=RC[-5]*RC[-3]+RC[-4]*RC[-2]"

Range("Q2:U2").Select
Selection.AutoFill Destination:=Range("Q2:U" & num_rows)
Columns("Q:R").NumberFormat = "0.0%"
Columns("S:U").NumberFormat = "0.0"

Sheets("Transactions").Visible = False
Sheets("SS-Calculations").Visible = False
Sheets("List of Items").Visible = False
End Sub
Sub New_ABC()
',
Dim num_rows, i, j As Integer
Sheets("SS-Calculations").Visible = True
Sheets("SS-Calculations").Select
num_rows = ActiveSheet.UsedRange.Rows.Count
Range("V1").FormulaR1C1 = "CSL prod"
Range("V2").FormulaR1C1 = ":=IF(RC[-15]=0,0,RC[-8]*RC[-5]/(RC[-15]*0.2)^2)"
Range("W1").FormulaR1C1 = "CSI spare"
Range("W2").FormulaR1C1 = ":=IF(RC[-16]=0,0,RC[-8]*RC[-5]/(RC[-16]*0.2)^2)"
Range("X1").FormulaR1C1 = "CSL tot"
Range("X2").FormulaR1C1 = ":=RC[-2]+RC[-1]"
Range("V2:X2").AutoFill Destination:=Range("V2" & num_rows)
Rows("1:1").Select
Selection.AutoFilter
   Key:=Range("X1"), SortOn:=xlSortOnValues, Order:=xlAscending, DataOption _
   :=xlSortNormal
With ActiveWorkbook.Worksheets("SS-Calculations").AutoFilter.Sort
   .Header = xlYes
   .MatchCase = False
   .Orientation = xlTopToBottom
   .SortMethod = xlPinYin
   .Apply
End With
Range("Y1").FormulaR1C1 = "index"
i = 2
j = 1
Do While i <= num_rows
   If Not Cells(i, 24).Value = "0" Then
      Cells(i, 25).FormulaR1C1 = j
      j = j + 1
   End If
i = i + 1
Loop
Range("Z1").FormulaR1C1 = "Rank"
Range("Z2").FormulaR1C1 = ":=RC[-1]/MAX(C[-1])"
Range("AA1").FormulaR1C1 = "NEW ABC"
'Range("AA2").FormulaR1C1 = 
""="IF(RC[-1]=0,""Ingen
1<=Användarformulär!R2C20,Användarformulär!R2C19,IF(RC[-
1]<=Användarformulär!R3C20,Användarformulär!R3C19,IF(RC[-
Range("AA2").FormulaR1C1 = _
"="IF(RC[-1]=0,""Ingen ABC"",""Användarformulär!R2C16",""Användarformulär!R3C16",""Användarformulär!R4C16",""Användarformulär!R5C16",""Användarformulär!R6C16",""Användarformulär!R7C16")"))

Range("AB1").FormulaR1C1 = "Pick-class"

'Range("AB2").FormulaR1C1 = _

Range("AC1").FormulaR1C1 = "New ABC"

'Range("AC2").FormulaR1C1 = _
""="IFNA(HLOOKUP(RC[-2],Användarformulär!R1OC19:R1OC25,RC[-1]+2,FALSE),0"

Range("AD1").FormulaR1C1 = "New Calculation"

Range("AD2").FormulaR1C1 = _
""="IF(RC[-17]=0,0,NORM.S.INV(RC[-17])*RC[-18]/SQRT(30)*(RC[-13]*SQRT(RC[-11])+RC[-12]*SQRT(RC[-10]))"

Range("AE1").FormulaR1C1 = "New SS, New ABC"

Range("AE2").FormulaR1C1 = _
""="IF(RC[-2]=0,0,NORM.S.INV(RC[-2])*RC[-19]/SQRT(30)*(RC[-14]*SQRT(RC[-12])+RC[-13]*SQRT(RC[-11]))"

Range("Z2:AE2").AutoFill Destination:=Range("Z2:AE" & num_rows)

Sheets("SS-Calculations").Visible = False

End Sub