Reducing Inventory and Optimizing the Lead time in a Custom order, High model mix Environment

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30 credits, Advanced level

Product and process development
Production and Logistics

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ABSTRACT

In this contemporary world, demand forecasting has become an effective tool for the success of any product organization. This is especially important when their components have long lead times and when the companies don’t build on order. The goal of this thesis is to reduce inventory by improving the forecast accuracy while maintaining customer lead time in a custom order, high mix model environment.

In this master thesis investigation, the research questions that were formulated are answered individually. To be able to answer the research questions, a thorough literature review was done to understand the various findings within this research area. In this thesis, only the high cost commodities were considered such as engines and frames as it costs an arm and a leg to have these high cost commodities in stock. Additionally, under estimating the forecast values of these components can be detrimental to business as the lead time of these high cost commodities are too long.

Firstly, the forecasting accuracy of previous years’ data is calculated and measured through forecast error measuring parameters such as cumulative forecast error, mean squared error, standard deviation of error, mean absolute deviation and mean absolute percentage error. In the empirical findings part of the thesis, the problems faced with the existing forecast method is briefed which highlights the root causes for overall forecast inaccuracy. Aforementioned forecasting problems inevitably increase the inventory level which is a serious threat to an organization due to working capital tie up.

Secondly, a hypothesis model was developed as an alternate forecasting model by considering the demand patterns from the past three years (historical) data. By analysing the demand pattern it was clear that the nature of the demand has been lumpy. A hypothesis model known as Croston’s model was developed and by applying the historical demand values, the forecast values were calculated. A key performance indicator known as mean absolute scaled error was calculated for both the existing and Croston’s forecast method for the purpose of comparison. The results proved that the Croston’s method gives better forecast accuracy when compared with the existing forecast method.

And finally, to improve the forecasting process as a whole, a benchmarking study has been successfully carried out. The benchmarking study is done with three internal companies within the Atlas Copco Group. The companies have been chosen by looking at the similarity in their product portfolio and business challenges faced

(Keywords: Forecasting, inventory management, forecasting methods, forecast accuracy lumpy demand)
ACKNOWLEDGEMENTS

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Shilpashree
Eskilstuna, 2016
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<th>Description</th>
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<tbody>
<tr>
<td>AC</td>
<td>Atlas Copco</td>
</tr>
<tr>
<td>AFE</td>
<td>Average forecast error</td>
</tr>
<tr>
<td>CC</td>
<td>Customer centre</td>
</tr>
<tr>
<td>CFE</td>
<td>Cumulative forecast error</td>
</tr>
<tr>
<td>ERP</td>
<td>Enterprise resource planning</td>
</tr>
<tr>
<td>KPI</td>
<td>Key performance indicator</td>
</tr>
<tr>
<td>MAD</td>
<td>Mean absolute deviation</td>
</tr>
<tr>
<td>MAPE</td>
<td>Mean absolute percentage error</td>
</tr>
<tr>
<td>MASE</td>
<td>Mean absolute scaled error</td>
</tr>
<tr>
<td>Mdh</td>
<td>Mälardalen University</td>
</tr>
<tr>
<td>MRE</td>
<td>Mining and rock excavation division</td>
</tr>
<tr>
<td>MRP</td>
<td>Material requirement planning</td>
</tr>
<tr>
<td>MRS</td>
<td>Mining and rock excavation services</td>
</tr>
<tr>
<td>MSE</td>
<td>Mean squared error</td>
</tr>
<tr>
<td>OR</td>
<td>Operation research</td>
</tr>
<tr>
<td>RCS</td>
<td>Rig control system</td>
</tr>
<tr>
<td>SED</td>
<td>Surface exploration drilling</td>
</tr>
<tr>
<td>SDE</td>
<td>Standard deviation of error</td>
</tr>
<tr>
<td>SRP</td>
<td>Strategic resource planning</td>
</tr>
<tr>
<td>SS</td>
<td>Safety stock</td>
</tr>
<tr>
<td>URE</td>
<td>Underground Rock excavation division</td>
</tr>
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</table>
1. INTRODUCTION

This chapter includes background, problem formulation, aim, research questions, project limitation and an outline of the thesis work is presented.

1.1 Background

Supply chain management is a theory that has evolved since the past few decades to enhance trust and partnership among the supply chain partners for better service and improved efficiency. The term “supply chain management” has become a buzzword in operations management strategy since early the 1980’s. According to Levy & Weitz (2009), in the supply chain retailers play a prominent role as they build a close link between the suppliers and the customers to ensure that goods are received on time and in the right quantity.

“Supply Chain Management consists of developing a strategy to organize, control and motivate the resources involved in the flow of services and materials within the supply chain” (Krajewski et al., 2006, p.372).

Davis (1993) mentions that in the supply chain system, there are various time derivative functions which often fluctuate and this affects the supply chain environment. One of the time derivative functions is the forecast. Due to the globalization and increased competitiveness, it is hard to predict the optimal forecast. It is a challenge for the manufacturing industry to deal with the imbalance between the forecast and the demand.

Inventory management is an integral part of the logistic system within the supply chain. Well-functioning inventory management plays an important role in measuring the organization’s ability to function with greater profit margin. Van Hoek et al (1998) mentioned that in the recent days, demand is one such variable which is tedious to forecast because of varying customer requirements. Due to the changing market condition and increased customer needs, the products need to be available with improved quality and sufficient quantity. The increased forecast inaccuracy has a greater impact on the inventory management. The inventory planning is dependent on the forecast made i.e. the estimation made to sell that many products. When the demand decreases, the stock level increases which results in decreased profit levels, losses can incur in the worst case.

The top level management in many organizations constantly faces problems in the strategic planning and decision making (Thomopoulos, 2015). The root cause for these problems is the uncertainty in the demand creating a challenge for the industries to improve their forecasting accuracy. Now with the improved technology, industries are allocating resources to measure their forecast accuracy and thereby trying to improve on that front. It can be noticed that there are various demand patterns which include smooth, intermittent, sporadic, lumpy etc. (Syntetos, et. al., 2005). Among these, the lumpy demand is the trickiest of all, and it has made the inventory planner’s life more difficult. Moreover it’s even more challenging for the organization to predict the forecast for those items which have lumpy demand for longer periods.

Hyndman (2009) defines forecasting as a process of “predicting the future event by relying on the availability of the past data”. According to Arnold et al., (2007), the forecasting is done for various purposes to meet the future demand. The important purpose is to be cost efficient and to have a sound production and resource plan. By estimating the forecast...
beforehand, it is possible to have the stock availability so that the products/services can be delivered to the customers at the earliest. The advantage of forecasting is that, it can reduce the production cost and have high service level and customer satisfaction (ibid).

According to Wallström & Segerstedt (2010), it is a challenge to build a flexible forecasting method to deal with the changes in the market condition. The effect of increased forecast error from the strategic plans is a critical issue, this makes a negative impact on an organization’s business economy and it has been a topic of interest for researchers (Holt et al., 1955). In the recent days the research studies based on improving forecast accuracy have gained popularity as it improves the economic status of organizations (Ritzman & King, 1993).

To get a clear understanding of the background of this problem and to highlight the root causes for the existing problem, a fish bone diagram is used. Below figure 1 shows the various root causes for the forecast inaccuracy.

**Root cause Analysis**

![Fish bone diagram for forecast inaccuracy](image)

**1.2 Problem formulation**

The root cause analysis shown above serves as a framework to formulate the problem in a better way. The biggest hurdle for any organization/industry would be meeting their customer demand in terms of service level and lead time by maintaining low inventory level. Inventory management plays a major role as it balances inventory and material availability. The root cause for the chain of problems is by following an inaccurate forecast. In this thesis, one of the main objectives is to shorten the product lead time for high mix low volume customized machinery.

Most of the product manufacturing companies especially within the mining sector employ the strategy of purchasing items on marketing forecast but with many variation and changes
this results in high inventory levels. The task is to analyze how forecasting can be effected looking only at long lead time/high cost items and what forecasting model can be used, assuming no accurate marketing forecast is available. The overall goal is to reduce or maintain equipment lead time while reducing inventory.

Main problem: How to deal with inventory build-up problems by improving forecast accuracy when there is an intermittent/lumpy demand?

1.3 Aim and Research questions

The aim of this thesis is to build a reliable forecasting model for companies with highly customized products with an intermittent/lumpy demand. In order to serve the aim of this thesis, the following research questions have to be answered.

Research question 1: What is the existing forecasting system at the case company and what are the problems faced with the existing forecasting system?

Research question 2: How accurate is the forecasting done by the case company in the past years?

Research question 3: Which existing forecasting models are there for handling lumpy demands?

Research question 4: What is the best alternate forecasting method that can be implemented to deal with the inventory issues?

1.4 Project limitations

This thesis work was performed in a span of 20 weeks from 2016-01-14 to 2016-05-31. Due to the limited time period, data collection for this project was limited and only few components were selected for forecast analysis. Further as a part of this thesis work the benchmarking was done and due to limited time the benchmarking done was only with 3 companies within the Atlas Copco Group. The external benchmarking was considered in the planning stage of this project, however all the companies who we contacted, with similar product portfolio were reluctant to share any information and therefore it is not a part of this thesis.

High level mathematical analysis is not a part of this thesis as the student’s mathematical knowledge is limited; having said that, the mathematical approach is used to derive many answers in this study but not to the advanced concept level.

1.5 Project Outline

This thesis report is split into six segments. At the outset, the methodology implemented to perform the study is explained. The next part sheds some light on the detailed literature review and the appropriate theory to understand the study. The data gathered in this study is used in the third part i.e. the empirical findings and later the result is presented. In order to get deep into the research question, hypothesis testing has been done and it is presented in the next section. To ensure the theory studied in this study is answerable to the research
questions, a clear analysis is done and it follows in the next section. To take this study into the next level a benchmarking study is done, it is presented in the next section. Last but not the least, the final part of the report is of course the conclusion, followed by suggestions on future works.
2. RESEARCH METHOD

In this chapter, the research methodology followed in this thesis work will be elucidated. It includes the methodological choice, the case study and the research strategy used for this thesis work. And finally the quality of the research in terms of validity and reliability is justified.

2.1 Methodological choice

“Research Methodology is a systematic way to solve research problem” (Kothari, C. R., 2004, p.8).

The goal of this master thesis in general is to build an alternate forecasting model for the companies that have highly customized products with intermittent/lumpy demand. In order to build a new forecasting model it’s essential to study the existing forecasting system. To study in depth about the existing system, in this case Strategic Resource Planning (SRP) driven forecasting system, all the required qualitative data had to obtained and studied. The historical quantitative data was also collected and analyzed for the purpose of empirical calculation. The quantitative data is also an integral part of this case study as the new suggested model depends on the previous historical data.

By reviewing the historical SRP forecasting method the forecast errors have been calculated, and later on Croston’s method has been used as a hypothesis tool. It is built in order to check if the forecast values yield better accuracy. Based on the literature studied, the hypothesis analysis was done to check the forecast accuracy. As a further step, the benchmarking process was also executed within the sister companies to review the potential performance improvement. Here in this thesis work, only process benchmarking is considered.

2.2 Case study

Ejvegård (2003) mentioned that reliability is often regarded as a precision measurement tool. He also stresses on the fact that the case study enables the researchers to focus on a particular problem and identify its connected roots and causes. In this thesis work, the case study is performed through benchmarking to study the forecasting process. The benchmarking process is explained in detail under the section 2.4.2. As a part of the research approach, the case study has been done in three internal benchmarking to deeply study the forecasting process and analyze the gathered information. Case study is used in various fields such as medicine, finance, manufacturing and many more. The purpose of performing a case study is to get a better understanding of a complex situation. According to Yin (2003), case study permits the researchers to maintain a reliable and holistic view of the day to day life affair. In short, it is a process of study in length and depth instead of breadth or width (Kothari, 2004).

The case study is mostly preferred for the qualitative research and it mainly focuses on the detailed investigation with a contextual setting approach. Case study is beneficial to deal with the qualitative research as it can be used to study in depth about the processes in the industries (Bryman & Bell., 2011). The qualitative case study enables the researchers to analyze the complex case by fragmenting it into segments within their area of specialization (Baxter & Jack, 2008). By performing the qualitative case study, the research topic gains
multiple visions to explore, which make it possible to disclose the multiple aspects to be studied and analyzed (Yin, 2003). The reason behind choosing the case study for this thesis work was to study the forecasting process of three internal companies within the Atlas Copco Group.

2.3 Case Company

The case company in this thesis work is Atlas Copco Rock Drills AB. Atlas Copco Rock Drills AB is a part of the Swedish industrial group Atlas Copco. Atlas Copco Group is a world leading provider of sustainable productivity. The parent company was founded in the year 1873. Atlas Copco Group companies have their headquarters in Stockholm, Sweden and the group is active in four main business areas, they are:

1. Compressor Technique
2. Mining and Rock Excavation Technique
3. Industrial Technique
4. Construction Technique

The Atlas Copco Group has close to 100 production sites in nearly 20 countries. It has ca 45 000 employees in 90 different countries and has its customers in nearly 180 countries. Sustainability and innovation are the core mantra of Atlas Copco. (Atlas Copco, History, 2016)

Atlas Copco Rock Drills AB comes under the umbrella of Mining and Rock Excavation Technique or Mining and rock excavation business area (MR) division. The company is based out of Örebro in the central part of the Sweden where it has its production facilities. At Örebro facility, they research, develop, manufacture and market rock drills, rock drilling rigs, trucks and loaders. Their products are used in both under and above the ground applications for mining, tunneling and construction purposes. They emphasize on customer service so there is a separate service division to be “first in mind- first in choice” (Atlas Copco Rock Drills AB, 2016).

Atlas Copco Rock Drills AB at Örebro can be further broken down into 4 divisions namely Rocktec, Underground Rock Excavation (URE), Surface and Exploration Drilling (SED) and Mining and Rock excavation Services (MRS). My thesis is carried out at URE division.

2.4 Data Collection

For an effective case study the data collected should be highly reliable else it can turn to be futile. Yin (2003) mentions that to perform a successful case study the researcher must possess excellent skills in the specialized area of research. The researcher should have the ability to extract the required data and find relevant sources to gather information. Gathering the data is a very crucial process in any research work. The data can be qualitative or quantitative in nature. The qualitative data is purely theoretical and it is mainly obtained by interviews, observation, books etc. The quantitative data is usually numerical and it is obtained from database sources such as company’s historical log book, e-files, transaction files etc. (Yin 2003, Trochim, 2006).

But to actually get started with the research process, it is important to study the literature in detail and identify the key areas in literature to perform the research. In this thesis work the case study is split into two segments. Firstly, the historical data have been collected from the
company’s Enterprise resource planning (ERP) system. Data from the year 2013 to 2015 was chosen for this analysis. Since the case company had loads of data, it is too tedious to slice the data for all the components. Hence only a few crucial high cost components were shortlisted for this study such as engines and frames. Thereby narrowing it down to few suppliers, the historical data was obtained, both the actual demand and the predicted forecast. Secondly, the case study in terms of the benchmarking process has also been performed. In this approach the information is gathered through interviews, emails, telephone meeting etc.

2.4.1 Primary and Secondary data

The data can be obtained both from primary and secondary sources. The data gathered by direct means or in person by observation or interviews is referred to as primary data. Data obtained from previous works i.e. mainly thesis reports, journals etc. is referred as secondary data (Kothari, 2004; Saunders et al., 2012). The availability of secondary data has been made easy in the past few years due to technological improvement or growth. Due to easy accessibility to research publication databases, it aids the researchers to obtain the secondary data sources (Bell, 1999).

It is essential to study the secondary data to get started and understand the theory behind the research topic even though the research work is mainly dependent on the primary data collected. But the secondary data can be used to analyze the result obtained from the research work which was obtained by using the primary data (Kothari, 2004). Usually in any research work both the primary and secondary data will be used by the researchers (Saunders et al., 2012). In this thesis work, the primary data is obtained through interviews, telephone and Webex meetings. It is explained in the section 2.4.4. The secondary data is obtained from the databases of Mälardalens University (MdH) and the documents that were accessed from case company’s homepage.

2.4.2 Literature Study

Literature study is the review of existing knowledge on a particular topic from various sources such as journals, articles, books, university database, library etc. (Hart 1998). It includes information such as the root source from where the specific literature has been extracted and its background information. In the literature review, there always exists a flow in the information which is useful to get a clear view of the topic and to proceed further in the investigation process. According to Kothari (2004), the literature study serves a backbone to perform the empirical calculations and achieve the results. By performing literature study, it makes one to easily understand the research problem and also to improve the overall methodology in the research work. Saunders et al., (2012) also mentions that dissertation reports and scientific journals aid to get a clear understanding of the theory behind the relevant area of research.

The summon database of MdH, google scholar, web of science, science direct, ABI/INFORM global, Scopus were some of the databases that were used to find the appropriate literature by using the key phrases such as forecasting, forecasting method, forecast accuracy, lumpy demand, inventory management etc.

This paper mainly focuses on building a forecasting model to improve the forecast accuracy when there is an intermittent demand. Hence many related articles on forecasting accuracy
have been studied deeply and explored. Also theory on benchmarking has been studied for further process investigation.

2.4.3 Benchmarking

“Benchmarking is the process of continuously evaluating and comparing one’s business process against comparable process in leading organizations to obtain information that will help the organization identify and implement improvements” (Andersen & Pettersen, 1995, p. 4).

Camp (1989) emphasizes that benchmarking is one of the powerful tools to review the best practices adopted by the industries to improve the overall performance. He stressed on the fact that the organizations observe the key business processes and tries to match their performance with the benchmarking organization. For example, most of the automotive industries have benchmarked with Toyota industries and have adopted their lean methodologies. According to Longbottom (2000), the benchmarking process is mostly done to improve the quality of the process. The four main stages in the benchmarking process as per Deming’s (1986) quality cycle are: Planning, Analyzing, Implementation and Review (ibid).

The figure below shows the different stages in benchmarking process.

---

![Benchmarking stages](image)

**Figure 2: Benchmarking stages (Czuchry, et al., 1995, p.39)**

Benchmarking process can also be categorized into 3 types, they are:

- External benchmarking
- Internal benchmarking
- Generic benchmarking

External benchmarking deals with evaluating the process with other organizations but within the same industry. Internal benchmarking is evaluating the process with a different department, division or business unit but within the same organization. Generic benchmarking deals with evaluating and analyzing the performance from a different organization and industry. But the core concept of all three types of benchmarking processes deals with understanding the process, observation, evaluation and analysis of the performance measures (Longbottom, 2000).
2.4.3.1 Internal benchmarking v/s External benchmarking:

“Spend your time looking in the mirror, not out the window” (Puckett III & Siegel, 1997, p.15).

Internal benchmarking can be used in large organizations where they have multiple business areas and different divisions which can be analyzed and compared with one another (Andersen & Pettersen, 1995). Internal benchmarking is used to compare the organizations working process internally. The company should be familiar with its own products, working principles, core values, etc. in order to compare with other organizations. It is the best practice to improve their process within the organization (ibid). The advantage of internal benchmarking is ease of access to data (Spendolini, 1992).

List of Respondents for Benchmarking:

<table>
<thead>
<tr>
<th>Company</th>
<th>Position of Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlas Copco Rock Drills AB</td>
<td>Supply chain Manager, Regional business Support, Production Planning &amp; Purchasing manager</td>
</tr>
<tr>
<td>Atlas Copco Company A</td>
<td>Logistic and Planning Manager</td>
</tr>
<tr>
<td>Atlas Copco Company B</td>
<td>Process Manager, Forecast to invoice</td>
</tr>
<tr>
<td>Atlas Copco Company C</td>
<td>Order-ToDelivery Manager</td>
</tr>
</tbody>
</table>

Table 1: List of respondents for Benchmarking

2.4.4. Interviews

Gathering information from interviews is one of the key sources to perform any research work (Yin, 2003). To get started with the benchmarking process it is important to prepare a set of interview questionnaire in order to gather the required information. Even though there are multiple ways to collect the information while performing a benchmarking process, it is stated that interview is one of the best practices (Andersen & Pettersen, 1995). The interview method requires minimum two persons i.e. the interviewer and the interviewee. Kothari (2004) mentions that there are two types of interviews conducted in a research process they are personal interview and telephone interview. He also mentions that the motive of conducting the interviews is that it should sway the research design and purpose.

- **Personal interview**: A personal interview is a method implemented in the qualitative research to gather information from the concerned authority. It is a conversation between two or more individuals in person. In this method the interviewer prepares a
set of questions in advance and asks the interviewee and gathers all the needed information (Kothari, 2004). This method is mostly preferred for intensive research analysis. In this method, the process of gathering information is done in a more structured manner.

- **Telephone interview:** A telephone interview method is also used to gather information for the research purpose. It is not regarded as the most common aid to perform the interview, but it is most commonly used in industry surveys when the locations are too far from each other (Kothari, 2004).

In this thesis, the interview questions were built by having a perception that it is a qualitative research. The designed interview questions were mostly open-ended which made the interviewee expressive in their answers with free flow of thoughts.

The interview questionnaires were built by intensely studying and understanding the foregoing research areas within forecasting. Also by studying relevant articles in this area to see what previous researchers have achieved and taking it a step further by involving new ideas, concepts and approaches to yield better results. It is constructed to get a clear vision about the research problem and to make it more interesting and captivating throughout the interview session. The questionnaires are included in the appendix section A.

### 2.5 Hypothesis test

A hypothesis test is regarded as the primary tool in research. Its purpose is to examine and experiment the available data by applying some theoretical knowledge (Kothari, 2004). According to Meriam (1988) a hypothesis test is a kind of case study that is performed to analyze the results obtained from the literature and empirical findings. There are various purposes to use the hypothesis testing, but the main purpose is to verify the findings in the research study.

In this thesis, for the first step the literature study was performed and as empirical evidence, forecast errors were measured by following the time series forecast calculation. As a next step, Croston’s method was introduced as hypothesis tool to check for improved forecast accuracy. The mean scaled error was measured and compared with the existing forecast and forecast obtained from Croston’s method. The hypothesis testing is done to prove the model, which was built by studying the relevant literature and by analyzing it. To perform the hypothesis test, the historical data was extracted from the company’s ERP system.

### 2.6 Quality of Research: Validity & Reliability

The quality of the research is measured by its reliability and validity. While performing a case study, validity and reliability relies on the researcher’s potential to make a project plan and execute it, problem solving approach and development of the conclusion. According to Merriam (1998), a qualitative research should be very precise so that the reader should be able to judge the drawn conclusions are logical or probable.

Data obtained in the research study must be tested logically in order to check if it is reliable and valid. The reliability is estimated by obtaining similar results when the experimental test repeats. Bell (1999) mentioned that test-retest method is the most common tool used to check the reliability of the research work. Validity is a tool which ensures that right thing is
measured that was planned in the project. It is also clear that if the data is not reliable then it cannot be valid. But the author also mentions that valid data is not always reliable (ibid).

The researchers build their tool for their research study and every developed tool has its own implication and they are unique. Hence the results obtained from the research study vary accordingly. Reliability in this thesis study is connected with a consideration by performing a qualitative research. Validity in this thesis is achieved by analyzing the results from the hypothesis and also by comparing it with the existing method.
3. THEORETIC FRAMEWORK

In this chapter the relevant literature study is covered which will be later used in the empirical part of the thesis work.

3.1 Forecasting:

Forecasting is widely used by all industries to plan their resources. By estimating the future they are better able to fulfill the customer demands (Jonsson & Mattsson, 2013). The forecasting can be seen in areas such as finance, marketing, production and the whole supply chain management. The forecast serves as an input to the planning model (Armstrong, 1985).

In this theoretical background only a few topics of forecasting will be touched, keeping the focus on improving the forecasting accuracy and method to improve the forecast accuracy. The theoretical framework includes the forecasting theory, different forecasting methods, forecast errors, how to improve forecast accuracy and performance and inventory management.

Some of the industries build their products based on the customer order received in general construction and mining industries follow certain forecasting techniques to predict the future customer demands and build their products as the customers do not wish to wait long to receive their orders (Arnold, et al., 2007). Forecasting is very essential for the decision makers when there is any uncertainty coming in the future (Armstrong, 2001). It is usually misinterpreted as planning by many, wherein planning is mainly concerned with “what the world should look like”, whereas the forecasting is mainly concerned with “what the world will look like” (ibid).

The forecasting methods can be used for the planning process to foresee the possible changes in outcomes allowing the creation of plan B/alternative plan. When right information is gathered by the planners in more structured or precise way they can have better preparation for future demands. Hence forecasting can be seen as very powerful tool in the decision making process to deal with reduction of the uncertainties that can occur (Jones & Twiss, 1978). But while choosing the forecast method one must adapt the flexibility to change their method while any lumpiness occurs in the demand. Hence it is ideal to consider the lumpiness factor while choosing any forecasting method (Ghobbar & Friend, 2003).

According to (Olhager, 2000), forecasting is done considering the previous historical data and the demand pattern may vary over the time. Hence before choosing any forecasting method it is important to consider the demand pattern. Krajewski et al (2006), mentions that a continuous occurrence of demand for any product can be observed by considering the historical data and this method of forecasting is known as time series forecasting. Thus by analyzing the repeatability in the demand under the time series, there are five different demand patterns (ibid). They are:

i) Level
ii) Trend
iii) Cyclical
iv) Seasonal
v) Random
The above mentioned demand patterns are illustrated in the figure below:

![Figure 3 Level demand pattern](Krajewski et al., 2006 pp.524)

![Figure 4 Trend Demand pattern](ibid)

![Figure 5 Cyclic demand pattern](ibid)

![Figure 6 Seasonal demand pattern](ibid)

![Figure 7 Random demand pattern](ibid)

Among these, the random demand pattern shown in figure 7 is the hardest off all to forecast (Mattsson & Jonsson, 2013). It has been an interest area of research to investigate the reasons for randomness and how to overcome and measure to deal with it. Few authors have linked these demand patterns with the inventory management strategies as it deals with stocking the products when such demand patterns occurs. It has led to ABC classification of the parts in the inventory; it will be covered in the section 3.8.1 of this report.
3.2 Forecasting Methods:

In general forecasting approach can be categorized into qualitative and quantitative methods. The forecasting methods used in the industry today falls under the above mentioned categories. There is no such best or optimal forecast method, each method has its pros and cons. Selecting the right method depends on factors such as previous forecast history, relationship with the suppliers, product forecast etc. According to Green (2001), while focusing on product forecasts, it is advisable to adopt a combination of few forecast methods.

3.2.1 Qualitative method

The qualitative method stresses on forecasting the future rather than illustration about the past (Makridakis & Wheelwright 1989). This method is applicable when there is no sufficient quantitative data available and instead there will be ample amount of qualitative information available (Masegosa, et al., 2013). This method is known as judgmental forecast, which mostly depends upon past experience, intuition/perception and knowledge without building any explicit forecast models. It is the most adopted forecasting method in most of the product companies these days (Dyussekenova, 2011).

If these subjective methods were not implemented then the quantitative method would give erratic forecasts (Krajewski et al., 2006). There are four main successful subjective forecast methods. They are: The Market study, salesforce estimates, executive opinion and the Delphi method (ibid).

3.2.1.1 Market Study

It is the most logical approach to gather information about the external customer needs in service or products by building and examining the hypothesis via data collection surveys (Krajewski et al., 2006). It comprises of constructing a list of interview questions, managing to grab all the possible information, choosing the right illustrative model, and mainly analyzing the gathered data either by subjective or statistical method in order to clarify the responses. Even though the market study gives the maximum useful information, it will still contain some barriers to get through (ibid).

3.2.1.2 Salesforce estimates

It is pretty clear that the foremost information about the future demand mainly comes from people who interact closely with the external customers (Krajewski et al., 2006). This forecast data is gathered from the customer centers, and they are reviewed by the sales company executives. It is regarded as a descended approach of the executive opinion method, wherein the information gathered by the sales executives or sales managers are taken into consideration for predicting the future demand (Kahn, 2003). By using these methods, there are many advantages as the salesforce is a group who are mostly highly knowledgeable about the future demand of the product/service that the customers will buy. Also, the forecast gathered by individual salesforce can be merged to find out the local, state or national sales (Krajewski et al., 2006). There are also certain drawbacks such as, for the salesforce it may be hard to interpret the difference between customer “wants” (wish list) and customer “needs” (buying list). (ibid)
3.2.1.3 Executive Opinion
It is a forecasting method where the judgements, views, opinions, work experience, scientific and practical knowledge of sales or production managers are merged together to attain a single precise forecast. It is a general practice when a new product or service is introduced to the market (Krajewski et al., 2006). At this instance, for the salesforce group it may be hard to make accurate forecast as it will not have any historical demand information. It is suggested that Executive Opinion is best suited for technological forecasting (ibid).

3.2.1.4 The Delphi method
It is one of the methods to obtain agreement from experts while not revealing their identity (Krajewski et al., 2006). This method is applicable when there is no availability of historical data to build any statistical models and if the managers have absolutely no background knowledge or experience to rely on the available forecast. In such cases, the concerned manager sends questions individually to everybody in the expertise group, where no personal identity is revealed of the organization or the person. The coordinator gathers the responses from every individual of the expertise group. The summary is made and further sent with more detailed queries for a second round of discussion. The process continues for few more rounds till final conclusions are made (ibid). This method is very similar to the executive opinion method as it considers the experts advice (Green, 2001).

This method is most efficient to improve long series forecast for product/service and also for forecast prediction of newly introduced products. This method is also best suited for technological forecasting (Krajewski et al., 2006).

3.2.2 Quantitative method
This method can also be regarded as an objective forecasting method. In this method, forecast is obtained mainly by data analysis (Ramström & Söderlund, 2001). The forecast from quantitative method can be implemented only when there is sufficient availability of the historical data (Krajewski et al., 2006). This historical data is known as a history file, which is stored in a certain commercial database. But when a new product is launched, then these history files may not be useful. In such instances, a subjective or judgmental forecast method may be beneficial to adjust the forecast that was gathered by quantitative methods. It is sub categorized into: statistical demand analysis model and time series method analysis.

3.2.2.1 Statistical demand analysis
This method takes into consideration the preceding and succeeding sales pertaining to the demand factors instead of considering time dependent factors. This method uses statistical approach to deal with the causing factors of sales fluctuation and other relative factors such as commodity price, revenue, advertising promotions etc. (Kotler, et al., 1999). Casual method such as linear regression method is most commonly used for statistical demand analysis. In this method it is possible to identify the influencing factors of forecasting and other relative external/internal factors (Krajewski, et al., 2006). In this method the relation between dependent and independent variable is expressed as a linear equation. It is represented as, \( Y = a + bX \)
Where, \( Y \) is dependent variable, \( X \) is independent variable, \( a \) is the y-intercept, \( b \) is slope of line (Krajewski et al., 2006 p. 529).
3.2.2.2 Time series method analysis

It is purely a statistical forecasting method which focuses on previous years historical data, irrespective of its correlation or bonding linked with the economic theory (Carnot et al., 2011).

This method uses the historical data concerned with only the dependent variables for the forecasting analysis (Krajewski, et al., 2006). By taking into consideration that there will be a possibility of a repeated pattern of the dependent variables the forecast values are estimated. The most common forecasting method that is adapted under time series is the naive forecast method. In this method the forecast approximated for the coming year is equivalent to the demand of the current year. For example while considering forecasting on a monthly basis, if the demand for January is 5 products then the forecasted demand for February is considered as 5 products. It is highly recommended for the demand which has seasonal trends. It is applicable when the trends are quite stable and degree of randomness is suitably low (ibid).

The statistical methods used for naive forecasting includes three methods they are: Simple moving average, weighted moving average, exponential smoothing.

3.2.2.2.1 Simple moving average

This method is used to calculate the average demand for a given time series in order to reduce the outcome of random variation in the demand. It is suitable when there are no seasonal or historical trends. If we consider n time period with demand \( D_t \), the forecast for next period \( F_{t+1} \) is calculated as,

\[
F_{t+1} = \frac{D_t + D_{t-1} + D_{t-2} + \ldots + D_{t-n+1}}{n}
\]

(Krajewski, et al., 2006 pp.532)

The figure below shows how the demand value varies over the time.

![Graph showing simple moving average](image)

Figure 8: Simple moving average (Krajewski, et al., 2006 pp.532)

3.2.2.2 Weighted moving Average method

In this method the weight of the demand varies significantly over the estimated time period. But the sum of the total weight is equal to unity. This method can handle seasonal trends with varied demand weights over the estimated time period. It is possible to prioritize the latest over the prior demand (Krajewski et al., 2006).

But, in the simple moving average the weight of demand remains constant over the estimated time period. Suppose the sum of weight of first estimated time period is 0.6, sum of weight of the second estimated time period is 0.3 and the sum of weight of third estimated time period is 0.1. Then the average forecast for the next period \( F_{t+1} \) is calculated as,
\[ F_{t+1} = 0.6D_t + 0.3D_{t-1} + 0.1D_{t-2} \ldots \] (Krajewski et al., 2006 pp.534)

### 3.2.2.2.3 Exponential smoothing method

This method is the advanced version of the weighted moving average method that is used to estimate average forecast for the next period by prioritizing the latest demand with increased weight over the prior demand. It is the most commonly used forecasting method when there is lumpiness in the demand (Gutierrez et al., 2008). In this method a smoothing constant \( \alpha \) is also considered to calculate the forecast for the period \( F_{t+1} \). The smoothing constant \( \alpha \) varies between 0 and 1 (Chopra & Meindl 2001).

It is calculated as,

\[ F_{t+1} = \alpha D_t + (1 - \alpha)F_t \ldots \] (Krajewski et al., 2006 p.534)

Where \( D_t \) is the current demand, \( F_t \) is the forecast for the last period and \( \alpha \) is the smoothing constant.

#### 3.2.2.2.3.1 Trend based exponential smoothing

In the time series method a trend is referred as standard variation in the average value over the estimated time (Krajewski et al., 2006).

This method is suitable when there is a trend following up with the demand forecast (Chopra & Meindl 2001). In order to compute the trend level it is essential to consider both the current and future estimate demand values. It involves exponential smoothing average of both trend and the series hence they are calculated individually and then the forecast value is calculated by adding the two parameters. It is calculated as,

\[
\begin{align*}
A_t &= \alpha D_t + (1 - \alpha)\left( A_{t-1} + T_{t-1}\right) \\
T_t &= \beta (A_t - A_{t-1}) + (1 - \beta)T_{t-1} \\
F_{t+1} &= A_t + T_t
\end{align*}
\] (Krajewski et al., 2006 p.536)

Where, \( A_t \) is the average exponential smoothed value for the time series for a period \( t \), \( T_t \) is the average exponential smoothed value of the trend for a period \( t \), \( \alpha \) is the smoothing constant for the average, \( \beta \) is the smoothing constant for the trend and \( F_{t+1} \) is the estimated forest for the time period \( t+1 \).

### 3.3 Forecasting errors

The purpose of using any forecasting method is to reduce forecast error and improve the accuracy. Measuring forecast error is one of the best practices. It is difference between actual demand and forecasted demand (Olhager, 2000). It is expressed as, \( E_t = D_t - F_t \)

Where \( D_t \) is the actual demand and \( F_t \) is the forecasted demand value. According to Mattsson & Jonsson (2013), if the difference between the actual and forecasted value is above zero or positive then it is said to have large error and if the difference value is below zero or negative then it is said to have very low error.

All the below formulas (i) to (vi) are referred from (Krajewski, et al., 2006, p. 541-542)

- **Cumulative forecast error (CFE):** It is the sum of all the error calculated over a time period \( t \). It is calculated as,

\[ CFE = \sum E_t \ldots \] (i)

It is used to measure the bias in the given forecast. It is more useful when we calculate the forecast error for a larger time period. It is observed that if the forecasted value
is smaller than the actual demand then the estimated forecasted error gets higher. As the error value remains positive then the CFE is apparently a larger value (Krajewski, et al., 2013). According to Harrison & Davies (1964), in order to estimate the bias between the fluctuating error the graph can be plotted to get a clear view of its randomness over the time period n.

- **Average forecast error (AFE):** It is also known as the mean bias error (Krajewski, et al., 2013). It is ratio of the cumulative forecast error to the total time period n. It is calculated as,
  \[ E = \frac{\text{CFE}}{n} \]  
  (ii)

- **Mean absolute deviation (MAD):** It is ratio of the absolute average forecast error to the total time period n. It is used to estimate the dispersion of the measured forecast errors. (Krajewski, et al., 2006). It is calculated as,
  \[ \text{MAD} = \frac{\sum \text{abs}E_t}{n} \]  
  (v)

It measures the magnitude of the errors. It is similar to the average forecast error but it does not take into consideration whether the error is positive or negative as it measures only the absolute error value (Mattsson & Jonsson., 2013). Because of the observed simplicity in calculation it is mostly used in the forecast accuracy calculations (Silver, et al., 1998).

- **Mean square error (MSE):** It is the most useful tool to measure the forecast accuracy (Silver, et al., 1998). It is calculated as,
  \[ \text{MSE} = \frac{\sum E_t^2}{n} \]  
  (iii)

It is observed that as the forecast error value increases the MSE also significantly increases as it is squared. (Krajewski & Ritzman, 2005). MSE estimates the variance of the average forecast error.

- **Standard deviation of error (SDE):** It is used to measure the variation from the average mean value (Lumsden, 2012).
  \[ \sigma = \sqrt{\frac{(E_t - \bar{E})^2}{n-1}} \]  
  (iv)

- **Mean absolute percentage error (MAPE):** It is used to estimate the correlation between the actual demand and forecasted demand. It is most commonly used for calculating the forecast accuracy (Krajewski & Ritzman, 2005). According to Chopra & Meindl (2001), MAPE is one of the best practices to estimate the forecast accuracy. He also proved that MAPE is an absolute average error and it is expressed in percentage. It is calculated as,  
  \[ \text{MAPE} = \frac{\sum \left( \frac{E_t}{D_t} \right)(100)}{n} \]  
  (vi)

- **Mean Absolute Scaled Error (MASE):** It is estimated as a percentage of the measured error by considering its absolute value and calculating the standard deviation of the given sample (Hyndman & Koehler, 2006). It can be used to compare the forecast that was achieved by the naïve forecast method. It does not rely on the calibration of the given data. The scaled error is measured as,
Scaled error, \( q = \frac{E_t}{\sum_{i=2}^{n-1}|y_i - y_{i-1}|} \) \ldots \ldots \ldots (vii) (Hyndman & Koehler., 2006, p.685)

The Mean absolute scaled error is the mean of the scaled error, it is calculated as
\[ \text{MASE} = \text{Mean}(|q|) \] \ldots \ldots \ldots (viii) (Hyndman & Koehler., 2006, p.685)

The authors proposed that MASE is a standard tool to measure the forecast accuracy while considering different series on varied scaled values. This calculation is valuable as it does not lead to any degeneracy and moreover it is the best tool used to compare different forecast methods (ibid).

3.4 Forecasting methods for lumpy demand:

Choosing the appropriate forecasting method is directly dependent on the nature of the demand (Syntetos et al., 2005). Willemain et al (2004) mentioned that to have an optimal inventory level it is important to forecast accurate demand values. But when there is a variation in the demand pattern it makes it hard to predict the accurate forecast. Moreover, predicting the forecast when there is an intermittent demand is a difficult job (ibid).

There are various forecasting methods that can be applied when there is an intermittent or lumpy demand. Most common forecasting methods are zero forecast method, exponential smoothing method, simple moving average, Bootstrapping, Croston’s method and few variations of Croston’s method (Teunter & Duncan, 2009). Among these Croston’s method (1972) is the first developed forecasting method to deal with intermittent demand. Croston (1972) was the very first researcher who recommended that the conventional methods such as, moving average and exponential smoothing are not feasible when it comes to slow-moving items. He proved that those methods can cause instability in the stocking decision. Zero forecast method was regarded as the weakest method of all as it does not consider positive integer values. The Bootstrap method was not a success as it generates a pseudo data without any variations even though there was no demand for extended period of time (Willemain et al., 2004).

Croston (1972) developed a new forecasting method for the products with intermittent or lumpy demand (ibid). Even though a few researchers have developed variations in the Croston’s method, it has not been successful. Teunter & Duncan (2009) mentioned that even after many variations that have been experimented by various researchers the original Croston’s method was appreciable.

3.5 Croston’s method of forecasting

Inventory problem dealing with products of irregular or lumpy demand is a common issue. Those products with the lumpy demand mainly include high cost components such as engines, axles, frames, dumpers or heavy machinery equipment etc. Improving forecast accuracy for these products with lumpy demand is the most important challenge in the inventory management (Vasumathi & Saradha, 2013).

Croston (1972) built a forecasting model for the products that have intermittence in their demand. He decomposed this method into parts, i.e. to measure the time interval between the demand periods and to calculate the forecast value when there existed a demand. Later on various authors such as Willemain et al (2004), Wallström & Segerstedt (2010), Synetos & Boylan (2005) etc. have clarified this method and have examined by applying the real
industrial data and have achieved incredible results. Few authors have modified it to some extent based on their findings from the past researches and achieved appreciable results. Croston’s method of forecasting is one of the best practices applicable for the products with intermittent or sporadic demand. Croston’s method was built mainly to establish accurateness to calculate mean demand over a time period (Willemain et al 2004).

Willemain et al (1994) had conducted a comparison study of Croston’s forecasting method with the exponential smoothing method in two different ways. Firstly, using the Monte-Carlo comparison he tried to build the algorithms in order to deviate from the assumptions made in Croston’s method with respect to the probability distribution. And secondly, by using industrial data from three to four different companies he tried to measure the forecast accuracy and compared it.

It was seen that the exponential smoothing method was most commonly used for inventory control of high volume products, but at times it can end up in the fluctuation in the stock levels (Willemain et al 1994). Croston’s method consist of two steps, first to estimate the average demand size by exponential smoothing and second to estimate the average time interval between the demand. According to Croston’s method the structure of demand is segmented into two factors, they are the meantime between the demand and the magnitude of the demand. The assumptions made in Croston’s method are the demand pattern follows the Bernoulli distribution and the size of the demand was assumed to have a normal distribution. The equation for average demand size and average meantime between demands is expressed as,

If \( X_t=0 \),
\[
D_t' = D_{t-1}' \\
P_t' = P_{t-1}' \\
s = s+1
\]

Else,
\[
D_t' = D_{t-1}' + \alpha (X_t - D_{t-1}') \\
P_t' = P_{t-1}' + \alpha (s-P_{t-1}')
\]

(Willemain et al., 2004, pp.379)

Where, \( X_t \) is the historical forecast from previous forecast, \( s \)- time difference between the two latest period with demand, \( D_t' \) is Croston’s approximation of average demand size, \( P_t' \) is Croston’s approximation of average meantime between demand, \( \alpha \)- smoothing factor (ibid).

By combing the above two computed values, the estimated mean demand per period is calculated as,
\[
F_t^* = \frac{D_t'}{P_t'}
\]

(3) (Willemain et al., 2004, pp.379)

3.6 Improving Forecast performance and accuracy

According to (Jacob et al., 1999), in order to achieve higher forecast accuracy it is essential to consider some important aspects. At times forecasting gets complicated and it will be hard to understand, in such instances the organization needs to consider that every individual working on forecasting has a different level of understanding. Hence in order to improve the forecasting performance level, it is pretty clear that the employee’s working on forecast get expertise from their work experience and knowledge from their workplace. Mainly by studying the earlier years forecasting patterns and having understood the past forecast errors it is possible to identify the necessary measures that can be solved and developed for the future forecast. (ibid)
According to Liker & Meier (2006), in this competitive world to be more efficient in the business area it is essential to have sound knowledge and proper guidelines or meet the company standards. The guidelines are normally built by adopting documentation; it is a set of instructions which gives a clear picture of the how the given task has to be executed. It is mentioned that without building a clear structure it is impossible to figure out the possible improvements (ibid).

According to Mentzer (2004), it is essential for every team member who works with forecasting to get personal feedback of their job performance. So that they get to know their area of improvement in order to improve the forecast accuracy. Moreover, it is also essential for them to know the negative impacts of poor forecast as it can hamper the whole loop such as inventory, capacity planning, production etc. Hence the author also stresses on the fact that, it is really important for the employees to perceive the purpose of forecasting who are working on it. They should understand how the footprint made by forecasting on the company and their customers. Also, the author makes a final note that, in order to succeed with improved forecast accuracy it is really essential to give training to the employees to improve the performance for those working with the forecast. By providing good qualitative training to the employees it is possible to improve the company’s forecast accuracy. (ibid)

**3.7 Strategic Resource Planning (SRP)**

The purpose of Strategic Resource Planning (SRP) is to predict the demand of a company’s products and services for an extended period of time, and planning the resource allocation in order to execute it in the most optimal way. According to Vancil & Lorange (1975) “Strategic resource planning (SRP) is defined as the process of gradual tapering of the tactical options that are intended to be fulfilled over the coming time period”. (ibid)

In the SRP driven forecast, there will be good blend of the market input and some speculations involved in the planning stage (Bucklin, 1965). In most of the profitable organizations, their key to success is knotted by effectively linking the forecast and the allocation of resources in an optimal way (Wacker & Lummus, 2002). The resources are determined by three main factors they are availability, capacity and location. These three parameters are the driving factors of the SRP system. In order to establish a successful resource plan, the planning is done in three stages and they are strategic, tactical and operational. It is shown in figure 9 (Owusu, et al., 2008).

These three core components of resource planning are interlinked and they communicate by sharing data between them. The figure below shows the relationship among the core components of resource planning.
Shaw et al., (1998) have mentioned that SRP is a tool that can be regarded as a process of review of various critical factors for success. SRP is a logical connecting process which requires two important ingredients and they are large number of investors and different sources to gather information such as market inputs from customer centers, macroeconomic data etc. There should be a good flow of information and coordination among the investors (Owusu, et al., 2008). When there is good coordination and true information is exchanged among the investors then it is a sign of making a successful strategic plan in any organization.

3.7.1 Importance of sales forecasting for Strategic Resource Planning (SRP)

The sales forecasting is a sub area under business forecasting (Armstrong, 1985). It is a process of predicting the future business sales that the organization intends to obtain. The sales forecast can be estimated on yearly, quarterly or monthly basis. Sales forecasting plays a crucial role in estimating the future demand, doing long term production planning of upcoming sales and to allocate the resources in an optimal way (ibid).

It is clear that for any manufacturing organization without the bond between forecasting and resource allocation it is not possible to gather enough resources in order to make delivery on right time to the customers (Wacker & Lummus, 2002). And the author also highlights that the role of sales forecast is really crucial, since it gives information about the future demand and based on that it is possible to build long term production planning. To be more precise, storing the right products to meet the sales is impossible without any pre-sales forecast. While implementing strategic thinking it is clear that company’s success relies on efficiency of the bonding between resource planning and forecasting. Strategic resource planning is done with the purpose that it reduces the forecast error which was obtained from the sales input (ibid).

3.8 Inventory management

The inventory management system focuses on three main aspects they are: How often the replenishment needs to be done, size of the replenishment order and how often the inventory status has to be reviewed (Silver 1981; Chatfield & Havya 2007).
Ideally the inventory management is concerned with other relative fields of operation management such as procurement of raw materials on time for production planning and scheduling, stocking of finished goods, determining the optimal stock levels and so on (Silver 1981). But with respect to operation research (OR), the inventory management is all about minimizing cost, maximizing profit, maximizing rate of return of stock investment and also to establish flexibility within the process. Most commonly identified constraints are reduced batch size, increased order quantity, poor customer service level, inventory space limitation, etc. (ibid).

According to Zanakis et al., (1980), there is always a gap between theory and practical implementation in inventory management. He suggests that the gap between the two can be connected between the two. It can be improved by implementing the following measures:

- Importance should be given to improve the stability of performance over the existing performance.
- The business analyst must strive hard to build and formulate a perfect model to achieve good results instead of finding an optimal solution.
- To ensure that everyone in the team is aware of the consequence of decision taking including the top and middle level of management (ibid).

Wagner (1980) noted that there existed several issues corresponding to the inventory management which could be improved. Few of the identified areas are:

- Statistical problems in inventory: This is most common issue in most of the inventory models. It is built on the assumption that demand patterns is constant and it has normal distribution, the bounds such as mean, standard deviation, variance are assumed to be constant, some invariable factors are assumed to be constant even though it changes over time. The only advantage of these assumptions is it reduces the control costs (Silver 1981).
- Lumpy demand: Most of the inventory models are built for smooth demand pattern, when the demand pattern fluctuates there exist uncertainty in the stock levels. When there is an erratic demand, the managers tend to increase the safety stock in such situations. But Croston (1972) has built a model when the demand drops to zero and further few more authors such as Brown (1977), Ward (1978) have developed models for this kind of intermittent demand patterns.
- Uncertainty in the supply: It is noticed that most of the inventory models are built on the assumption that the replenishment items are received more close to its lead time, but due to some delays it exceeds its overall lead time and thus results in scarcity in the stock levels. Hence the importance should be given to the decision making process so that the stock arrives at right time in right quantity (Silver 1981).
- Interface with marketing: There are three main issues associated within this are, how to deal with promotional events, predicting the demand pattern when new products are introduced and allotment of shelf size for replenishment. They are mutually related and affect the sales forecasting (Silver 1981).
- Incorporated logistics: As mentioned by Clark (1972), inventory management is the integral key of supply chain and logistics systems which involve transportation/shipment, maintenance, production etc. As it is interrelated with many departments the concern is how to build a successful model for the decision making process for such a complex scenario (Warner 1980).
3.8.1 ABC Classification

Commodities are categorized into different batches or product groups in most of the organizations in order to avoid misplacement of the stocked items, and to ensure that they have the optimal material handling system. ABC classification is the most common classification method used in inventory management. It is the process of dividing the articles into 3 different levels ranked on its profitability. It means to figure out the different product groups based on the level of profit it makes to the company. The figure below shows the ABC analysis, the product group A has the highest dollar value but it represents only 20% volume. The product group B represents around 30% of the volume and has a lower dollar value. The product group C represents 50% of the volume and has lowest dollar value ranging around 5%. In addition to material handling, ABC classification is used to find the optimal inventory level of class A so that the organization can achieve greater profit margins (Krajewski et al., 2006).

The figure below shows the ABC parts categorization to achieve optimal inventory level.

![Figure 10: ABC Classification, (Krajewski, et al., 2006, p.469)]](image-url)
4. EMPIRICAL EVIDENCE

This chapter begins with brief introduction of the case company and their forecasting process. The main emphasis of this section is to brief about their existing forecasting process.

4.1 The Company Atlas Copco-URE division

URE develops, manufactures and markets a wide range of tunneling and mining equipment for various underground applications all over the world. New generation products are highly automated using latest platforms such as rig control system (RCS 5). As mentioned earlier URE is a division under the business unit Mining and Rock Excavation Technique as described in the picture below.

![Classification of different business units under Mining and rock excavation technique](image)

Figure 11: Classification of different business units under Mining and rock excavation technique (Atlas Copco, 2016)

The table below illustrates some of the product range of Underground Rock Excavation division at Atlas Copco Rock Drills AB. They are specialized in offering a complete range of products for underground mining and construction projects for all types of customers at all corners of our planet.

<table>
<thead>
<tr>
<th>Product name</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boomer</td>
<td>- Tunnel drilling (Infrastructure)</td>
</tr>
<tr>
<td></td>
<td>- Mine transport route drilling</td>
</tr>
<tr>
<td></td>
<td>- Ore body drilling</td>
</tr>
<tr>
<td>Simba</td>
<td>- Long hole drilling</td>
</tr>
<tr>
<td></td>
<td>- Ring drilling</td>
</tr>
<tr>
<td>Product Range</td>
<td>Features</td>
</tr>
<tr>
<td>--------------</td>
<td>---------</td>
</tr>
</tbody>
</table>
| Rock reinforcement (Boltec) | • Bolting hole drilling  
• Bolt setting  
• Cable setting |
| Hägglader | • Continuous loading |
| Loader | • Loading, hauling and dumping in all types mining and construction applications |
| Mine truck | • Transportation in production mining  
• Transportation in construction projects |
| Raiseboring | • Slot raise, backfilling, narrow vein mining applications  
• Block cave, sub level caving  
• Raise boring |

Table 2: Product range of URE division at Atlas Copco
4.2 SRP forecast at Atlas Copco

Atlas Copco URE division follows the SRP method of forecasting. For this method the market forecast is the basic input. It is mainly concerned with the strategic planning that is done in different levels to make a successful resource plan. The above figure shows the detailed view of the case company’s forecasting process.

The forecasting process starts from the information gathered at the customer centers (CC) all across the globe. The information is collected by the marketing team frequently and then the gathered information is all merged together. Here the marketing team makes the final subjective forecasting list which is based on certain aspects such as commodity pricing. At this stage certain filtration and addition will be done from the market forecast data. The SRP is done by considering various factors such as market outlook, probability of purchase, etc.

Once the SRP forecast is done it is passed on to the production and purchasing department. Weekly updates are done by conducting a meeting with the production team regarding the availability of material and production capacity. The production department is mainly concerned with the capacity planning, where in they take care of factors such as availability of resources, physical space, etc. The purchasing team starts their work by ordering the material based on the SRP forecast. Finally the Material requirement planning (MRP) is made followed by a material plan, further orders are placed to the sub suppliers. The above figure 12 shows the clear image of the case company’s forecasting process. For some items, in addition to SRP Safety stock (SS) is calculated as:

\[ SS = \frac{\text{Daily demand}}{240} \times \text{Lead time} \times K \text{-factor} \]

K-factor is assumed as 0.5 and 240 is the number of working days in a year.
4.3 Empirical Result

Forecast Errors:

In this case study, the forecast errors are measured for the chosen high cost commodities such as engines and frames. From the company’s ERP system, the forecast and the actual demand values from the period (2013-2015) were obtained. By following the time series forecasting method, the forecast errors have been calculated. It is observed that from the past three years due to market conditions there is lumpiness in the demand for their products. Due to this situation, predicting the demand forecast is a tedious job. In order to improve the forecast accuracy it is important to reduce the forecast errors.

To begin with the empirical calculation, required data is downloaded from the company’s ERP software known as M3. The information from M3 were is article number, name of the commodity, order entry date, transaction date, order category, transaction quantity etc. This information is extracted from the M3 software and drafted into a excel spread sheet for further investigation. From this information the forecast and the actual demand on monthly basis from the period (2013-2015) was determined. Later, the forecast and demand values were transferred to a new excel sheet and the forecast errors were calculated.

From the calculated forecast error and a series of other time series forecast measures were calculated, which includes:

- Cumulative forecast error
- Average forecast error
- Mean squared error
- Standard deviation of error
- Mean absolute deviation
- Standard deviation of the errors
- Mean absolute percentage error

In order to measure the forecast accuracy it is important to calculate the forecast errors and the relative key performance indicators (KPI’s) such as Mean absolute deviation, Mean square error, Mean absolute scaled error and Mean absolute percentage error. The company produces around 100 products which comprise of around 100,000 part numbers. But due to the time limitation only a few high cost components are chosen for this thesis work. In this thesis work, the forecast error calculations have been done for engines, and frames.

Engines: It is a high cost commodity used for the underground mining equipment. The engine is an integral part of any mining equipment. The case company utilizes Cummins, Detroit Diesel and Deutz engines in a range of sizes from 4 to 19 liter capacity. The figure below shows one of the most commonly used engine in their mining machinery.
The lead time for these high cost components are usually long; it takes around 3-4 months from the supplier once the order is placed. Hence, in order to deliver the products to the customer within the expected time it is essential to have an accurate forecast. The forecast errors are measured for the case company’s engines. Since the company’s products are highly customized there exists not much commonality in their parts. There are nearly 83 different engines and the forecast error for the engines are calculated manually and presented in the appendix.

By downloading the forecast and the actual demand from the company’s ERP system from (2013-2015), and by following the time series forecast method the various forecast errors were calculated by using the relevant formulas. Below the lowest and the highest limit of the values are presented:

<table>
<thead>
<tr>
<th>Forecast error measure</th>
<th>Lowest</th>
<th>Highest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative forecast Error</td>
<td>-452</td>
<td>47</td>
</tr>
<tr>
<td>Average forecast error</td>
<td>-12.56</td>
<td>10</td>
</tr>
<tr>
<td>Mean squared error</td>
<td>-0.39</td>
<td>5675.11</td>
</tr>
<tr>
<td>Standard deviation of error</td>
<td>0.07</td>
<td>92.58</td>
</tr>
<tr>
<td>Mean absolute deviation</td>
<td>0.03</td>
<td>62.06</td>
</tr>
<tr>
<td>Mean absolute percentage error (%)</td>
<td>0.08</td>
<td>424.87</td>
</tr>
</tbody>
</table>

Table 3: Forecast error measure for engine

The time duration for all the part numbers used in time series calculation is the same 36 months. Some part numbers have very low demand and in some cases the time interval between the demand is very high, this leads to an error close to zero. For a few articles there is no demand at all in such case the related error measures tends to zero. There exists few part numbers which have steady demand but with some variation in the forecast and demand value and those part numbers tend to have very low error values. Furthermore, there are few engines with absolute zero demand for a certain period of time and suddenly receives a small number of demand. These articles are said to have lumpy or intermittent demand where the demand is zero over an extended period of time.
**Frames:** It is a high cost commodity which comes under the parts of the mining machinery. The figure below shows one of the body frames that is commonly used in their mining equipments. There are various types of frames used in the mining equipment, based on their application they are grouped and categorized.

The forecast errors are calculated for the frames and it presented in the appendix part of the thesis.

By downloading the forecast and the actual demand from the company’s ERP system from (2013-2015), and by following the time series forecast method the various forecast errors were calculated by using the relevant formulas. Below the lowest and the highest limit of the values are presented:

<table>
<thead>
<tr>
<th>Forecast error measure</th>
<th>Lowest</th>
<th>Highest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative forecast Error</td>
<td>-85</td>
<td>11</td>
</tr>
<tr>
<td>Average forecast error</td>
<td>-0.81</td>
<td>0.31</td>
</tr>
<tr>
<td>Mean squared error</td>
<td>0.42</td>
<td>35.97</td>
</tr>
<tr>
<td>Standard deviation of error</td>
<td>0.62</td>
<td>2.03</td>
</tr>
<tr>
<td>Mean absolute deviation</td>
<td>0.25</td>
<td>2.97</td>
</tr>
<tr>
<td>Mean absolute percentage error (%)</td>
<td>2.78</td>
<td>23.38</td>
</tr>
</tbody>
</table>

Table 4: Forecast error measures for frames

From analyzing these results, a hypothesis tool is built to deal with these forecast inaccuracy issues. For the hypothesis testing only few articles are selected which have a high level of randomness and they are investigated in detail. It is explained in the next section.
5. HYPOTHESIS TESTING

The hypothesis is built mainly by analyzing the gathered data and studied literature. Hence a hypothesis tool was developed to measure the forecast accuracy and it was tested. First it begins with the introduction of the hypothesis tool and purpose of adopting it in this thesis study and later the result will be presented.

In this thesis, a case study at Atlas Copco was performed by building a hypothesis tool to deal with their forecasting and inventory issues. The case company follows the SRP driven forecasting method. Due to the lumpiness in the demand they have a poor forecast accuracy which leads to increased inventory levels. Sales forecast is a basic input for their forecasting system. As the business market fluctuates, it is hard for industries to predict the right forecast values. Due to this fluctuation, the marketing team working has to review some business cooking to predict the right forecast value. Sometimes, the past historical forecast value can be useful when the market condition remains steady, or else to overcome this situation additional review and modification has to be done. Due to this disturbed market condition, there will be an uncertainty in the demand making it hard to find the right forecast for the industries. The case company produces a wide range of underground mining equipment and all their products are highly customized. As a result there exists not much commonality in their parts hence it’s a challenge for them to maintain their inventory level by building right amount of safety stock. So far, they have not made any attempt to measure their forecast accuracy, it is mainly because the varied number of products and options. The annual forecast review is now done on monthly basis and it is fed to their ERP system known as M3. And later even on daily basis the forecast values are manipulated based on the orders received by their customers. Atlas Copco’s URE division produces 100 products which consist of nearly 100,000 part numbers.

5.1 Building/Initiation of a hypothesis tool:

As there are quite a lot of part numbers only a few high cost commodities was targeted for this thesis work. Due to the company’s customized products each commodity had varied part numbers and it was a tedious job to do it manually. And further, prioritizing those part numbers which had high level of intermittence was a herculean task. Once those part numbers were chosen for the hypothesis testing, the demand and forecast values were extracted from the company’s ERP system. The hypothesis tool was drafted in the Microsoft Excel program 2010. The Microsoft Excel is an excellent program that can be used for calculation when dealing with heavy data. Beare (1991), mentioned that an Excel spread sheet is designed in such a way that it makes one easy to analyze the statistical data and it also serves as a support for databases.

Hence the forecast calculation was done in Microsoft excel sheet by inserting the relevant formulas needed for the calculation. In this method the demand calculation was modified by incorporating a smoothing parameter in the equation and then the forecast was estimated. It was then transferred to a new Microsoft Excel sheet and the scaled error was calculated for the existing SRP method, then a separate forecasting using Croston’s method was calculated. For the new built Croston’s method the mean absolute scaled error was calculated and a comparison was made with the existing forecast method. The mean
absolute scaled error is a forecast accuracy measuring tool; hence a comparison is done for both the methods.

5.2 Purpose of building the hypothesis tool

The purpose of this tool is to measure the forecast performance in terms of mean absolute scaled error and justify that it yields better forecast accuracy when there is lumpiness in the demand. In order to improve the forecast accuracy, the Croston’s method was used and a comparison is done with the existing forecasting values of the case company.

5.3 How the hypothesis tool works

The required data is downloaded from the company’s ERP software known as M3. The information from the M3 was the article number, name of the commodity, order entry date, transaction date, order category, transaction quantity etc. This information is extracted from the M3 software and drafted into an Excel spread sheet for further investigation. From this information the forecast and the actual demand on monthly basis from the period 2013-2015 is determined. Later the forecast and demand values are transferred to a new Excel sheet and the forecast errors are calculated. Furthermore, the mean demand size and the average demand interval was calculated. Below the hypothesis model initialization is shown:

<table>
<thead>
<tr>
<th>Model initialization:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Model name</td>
<td>Croston’s Model</td>
</tr>
<tr>
<td>Model parameters</td>
<td></td>
</tr>
<tr>
<td>X_t - Historical forecast from previous forecast</td>
<td></td>
</tr>
<tr>
<td>P'_t - Croston’s approximation of demand interval.</td>
<td></td>
</tr>
<tr>
<td>F'_t - Croston’s approximation of estimated forecast.</td>
<td></td>
</tr>
<tr>
<td>D'_t - Croston’s approximation of average demand size.</td>
<td></td>
</tr>
<tr>
<td>s- time interval since the last transaction has occurred</td>
<td></td>
</tr>
</tbody>
</table>
| Condition | If X_t=0 ; X_t=X_{t-1} , P'_t =P'_t-1 ; 
then s=s+1;

Else, D'_t =D'_t-1 +α (X_t-D'_t-1 ) ;
P'_t =P'_t-1 +α (s-P'_t-1 ) ;
Endif |
| Result: Average forecast | F'_t = D'_t / P'_t |

Table 5: Croston’s model (Willemain et al., 2004, p.379)

Croston’s method is done in two steps. In the first step, a separate exponential smoothing is done for all the demand values and the average demand per period is calculated. In the second step, the average of the time interval between the demand periods is calculated. It is calculated on the condition that if the demand of the estimated time period is zero, then it refers back to the previous month forecast, and if the demand value is greater than zero then it is calculated using the built formula.
According to Bernoulli’s process, the probability function of the trial depends upon the occurrence of the demand. In other words, the Bernoulli trial has a fixed probability when there is a positive demand or else the demand is zero (Janssen, et. al., 1998).

Silver et al., (1998) & Willemain et al., (2004) mentioned that if we consider a demand as a Bernoulli’s process then the probability of the outcome of its trial is 1/p or (1-1/p), i.e. if the demand is independent between the time intervals then the probability that the demand occurs is 1/p and the probability if the demand does not occurs is (1-1/p). Thus by referring this principle to the Croston’s method, the process can be simplified further:

If the Demand is zero, (D=0) then
\[ D'_t = D'_{t-1} \quad \text{and} \quad P'_t = P'_{t-1} \]

If the Demand occurs, (D>0) then
\[ D'_t = \alpha X_t + (1- \alpha) D'_{t-1} \quad P'_t = \alpha s + (1- \alpha) P'_{t-1} \]

Hence the Forecast is calculated as, \[ F_t^* = \frac{D'_t}{P'_t} \]

(Silver et al., 1998 & Willemain et al., 2004)

By applying this hypothesis tool to the real data, the demand values are smoothed by inserting a smoothing parameter in the above equations and also the time interval between the demand periods will be modified. The table below shows how the calculation is done:

The hypothesis test for one article is presented below and the rest of the selected articles are included in the appendix part of the thesis.

<table>
<thead>
<tr>
<th>Time (months)</th>
<th>Actual Demand (X_t)</th>
<th>Time interval between demand (s)</th>
<th>Croston’s forecasted demand value (F_t^*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.00</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>12.00</td>
<td>1.00</td>
<td>11.70</td>
</tr>
<tr>
<td>3</td>
<td>11.00</td>
<td>1.00</td>
<td>11.73</td>
</tr>
<tr>
<td>4</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>5</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>6</td>
<td>5.00</td>
<td>3.00</td>
<td>6.65</td>
</tr>
<tr>
<td>7</td>
<td>0.00</td>
<td>0.00</td>
<td>0.99</td>
</tr>
<tr>
<td>8</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>9</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>29.00</td>
<td>4.00</td>
<td>28.19</td>
</tr>
<tr>
<td>11</td>
<td>10.00</td>
<td>1.00</td>
<td>12.79</td>
</tr>
<tr>
<td>12</td>
<td>0.00</td>
<td>0.00</td>
<td>1.51</td>
</tr>
<tr>
<td>13</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>14</td>
<td>3.00</td>
<td>3.00</td>
<td>2.51</td>
</tr>
<tr>
<td>15</td>
<td>0.00</td>
<td>0.00</td>
<td>0.09</td>
</tr>
<tr>
<td>16</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
The hypothesis test is done for some selected part numbers and further the Mean absolute Scaled error is calculated. MASE determines the forecast accuracy. It is calculated using the formula,

\[ MASE = \text{Mean} \left( \frac{E_t}{n-1} \sum_{i=2}^{n} |Y_{i-1} - Y_{i-2}| \right) \] ............(Hyndman & Koehler., 2006, p.685)

### 5.4 Result from hypothesis test

By following the above mentioned formula, the MASE value was calculated. MASE is used to measure the forecast accuracy; it is calculated as the ratio of the mean absolute error of the true forecast to the mean absolute error of the sample obtained by the naive method. The MASE of the existing forecast and for the forecast calculated by Croston’s method is calculated and compared. The hypothesis testing is done only for few part numbers and one of the part numbers is presented below:

<table>
<thead>
<tr>
<th>Period</th>
<th>Actual Demand</th>
<th>SRP forecast</th>
<th></th>
<th>Croston forecast</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Forecast</td>
<td>Abs Scaled error</td>
<td>MASE</td>
<td>Forecast</td>
<td>Abs Scaled error</td>
</tr>
<tr>
<td>1</td>
<td>9.00</td>
<td>0.00</td>
<td>2.66</td>
<td>1.04</td>
<td>0.00</td>
</tr>
<tr>
<td>2</td>
<td>12.00</td>
<td>11.00</td>
<td>0.27</td>
<td>11.70</td>
<td>0.39</td>
</tr>
<tr>
<td>3</td>
<td>11.00</td>
<td>18.00</td>
<td>1.92</td>
<td>11.73</td>
<td>0.43</td>
</tr>
<tr>
<td>4</td>
<td>0.00</td>
<td>11.00</td>
<td>3.03</td>
<td>1.00</td>
<td>0.90</td>
</tr>
<tr>
<td>5</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
<td>0.90</td>
</tr>
<tr>
<td>6</td>
<td>5.00</td>
<td>1.00</td>
<td>1.10</td>
<td>6.65</td>
<td>0.47</td>
</tr>
<tr>
<td>7</td>
<td>0.00</td>
<td>20.00</td>
<td>5.51</td>
<td>0.99</td>
<td>0.46</td>
</tr>
<tr>
<td>8</td>
<td>0.00</td>
<td>9.00</td>
<td>2.48</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>9</td>
<td>0.00</td>
<td>6.00</td>
<td>1.65</td>
<td>0.00</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Table 6: Croston’s demand forecast
Table 7: Comparison of SRP forecast v/s Croston’s forecast

<table>
<thead>
<tr>
<th>Period</th>
<th>SRP Forecast</th>
<th>Croston’s Forecast</th>
<th>MASE</th>
<th>Relative Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>29.00</td>
<td>27.00</td>
<td>0.55</td>
<td>28.10</td>
</tr>
<tr>
<td>11</td>
<td>10.00</td>
<td>21.00</td>
<td>8.54</td>
<td>12.79</td>
</tr>
<tr>
<td>12</td>
<td>0.00</td>
<td>7.00</td>
<td>1.92</td>
<td>1.51</td>
</tr>
<tr>
<td>13</td>
<td>0.00</td>
<td>1.00</td>
<td>0.27</td>
<td>0.00</td>
</tr>
<tr>
<td>14</td>
<td>3.00</td>
<td>1.00</td>
<td>0.55</td>
<td>2.51</td>
</tr>
<tr>
<td>15</td>
<td>0.00</td>
<td>1.00</td>
<td>0.27</td>
<td>0.09</td>
</tr>
<tr>
<td>16</td>
<td>0.00</td>
<td>1.00</td>
<td>0.27</td>
<td>0.00</td>
</tr>
<tr>
<td>17</td>
<td>0.00</td>
<td>1.00</td>
<td>0.27</td>
<td>0.00</td>
</tr>
<tr>
<td>18</td>
<td>0.00</td>
<td>1.00</td>
<td>0.27</td>
<td>0.00</td>
</tr>
<tr>
<td>19</td>
<td>0.00</td>
<td>1.00</td>
<td>0.27</td>
<td>0.00</td>
</tr>
<tr>
<td>20</td>
<td>0.00</td>
<td>1.00</td>
<td>0.27</td>
<td>0.00</td>
</tr>
<tr>
<td>21</td>
<td>2.00</td>
<td>1.00</td>
<td>0.27</td>
<td>1.56</td>
</tr>
<tr>
<td>22</td>
<td>5.00</td>
<td>1.00</td>
<td>1.10</td>
<td>6.60</td>
</tr>
<tr>
<td>23</td>
<td>3.00</td>
<td>3.00</td>
<td>0.00</td>
<td>3.04</td>
</tr>
<tr>
<td>24</td>
<td>0.00</td>
<td>2.00</td>
<td>0.55</td>
<td>0.09</td>
</tr>
<tr>
<td>25</td>
<td>0.00</td>
<td>1.00</td>
<td>0.27</td>
<td>0.00</td>
</tr>
<tr>
<td>26</td>
<td>2.00</td>
<td>1.00</td>
<td>0.27</td>
<td>1.04</td>
</tr>
<tr>
<td>27</td>
<td>0.00</td>
<td>1.00</td>
<td>0.27</td>
<td>0.04</td>
</tr>
<tr>
<td>28</td>
<td>0.00</td>
<td>1.00</td>
<td>0.27</td>
<td>0.04</td>
</tr>
<tr>
<td>29</td>
<td>0.00</td>
<td>1.00</td>
<td>0.27</td>
<td>0.04</td>
</tr>
<tr>
<td>30</td>
<td>0.00</td>
<td>1.00</td>
<td>0.27</td>
<td>0.04</td>
</tr>
<tr>
<td>31</td>
<td>0.00</td>
<td>1.00</td>
<td>0.27</td>
<td>0.04</td>
</tr>
<tr>
<td>32</td>
<td>0.00</td>
<td>1.00</td>
<td>0.27</td>
<td>0.04</td>
</tr>
<tr>
<td>33</td>
<td>0.00</td>
<td>1.00</td>
<td>0.27</td>
<td>0.04</td>
</tr>
<tr>
<td>34</td>
<td>2.00</td>
<td>0.00</td>
<td>0.55</td>
<td>3.04</td>
</tr>
<tr>
<td>35</td>
<td>0.00</td>
<td>1.00</td>
<td>0.27</td>
<td>0.04</td>
</tr>
<tr>
<td>36</td>
<td>0.00</td>
<td>1.00</td>
<td>0.27</td>
<td>0.00</td>
</tr>
</tbody>
</table>

By looking at the above forecast values and comparing the SRP forecast and Croston’s forecast with the actual demand we can see the difference. Say we consider period 2 the actual demand is 12 units and the SRP forecast was 11 and the suggested Croston’s forecast was 12. So there is a forecast error of 1, it is short by 1 unit which can be a risk to lose business. If we look at period 3, the actual demand was 11 and the SRP forecast was 18 units and the suggested Croston’s was 12. In this case, there is a forecast error of 6 units it means the forecast value is over estimated. These extra 6 units costs nearly 1,200,000 SEK and it is a tied up capital in the inventory. Whereas in the Croston’s method the suggested forecast was 12, it still has an error of 1 unit. But still it is better than having extra 6 units in inventory. In this business world, at the end of the day everything boils down to money hence overstocking the inventory is more like having the capital in shelf and its static. But on the other hand, underestimating the forecast is not a good choice; there is a high risk to lose the business. As these high cost components have long lead time, it will take a really long time the deliver the products to the customer and likewise the customers don’t wish to wait that long. So forecasting the right number is really essential to avoid inventory pileups and also to deliver the products to the customers at the earliest.

From the MASE value obtained both for the existing forecast and the Croston’s forecast it can be proved that the Croston’s method of forecasting yields better forecast accuracy.
Hyndman & Koehler (2006) mentioned that when the MASE value is less than 1, the forecasting method has reduced errors or low errors which means it has better accuracy.
6. ANALYSIS

The purpose of this chapter is to answer each research question built in this thesis work. The research questions are answered below.

1. What is the existing forecasting system at the case company and what are the problems faced with the existing forecasting system?

From the empirical part of the report, it is clear that the case company follows an SRP method of forecasting. The forecasting is done for a global market and later the categorization is done based on global, regional and national levels. For the underground mining division the forecasting is done by the regional business support in Örebro, Sweden. Once the marketing team gathers the information the compilation is done along with some modification based on market trend.

SRP forecasting is a combination of marketing forecast and some speculation involved in the process (Bucklin, 1965). This enables the case company to place an order to their suppliers before they actually receive the order from their customers. According to Wacker & Lummus (2002), for product organizations to place an early order before they actually receive the order from the customer in a supply chain is possible only when there is a good blend of market input and some speculations. The advantage of using this method of forecasting leads to reduction in production cost as bulk orders are economical because of eventual reduction in transportation and material handling cost (Dugic & Zaulich, 2011; Green 2001).

By estimating the forecast earlier, the company can avoid losing their business when the customer intends to receive it within a short duration of time. When the products are already in stock it can be delivered as soon as the customer places the order which makes the customer happy and satisfied (Dugic & Zaulich, 2011).

According to (Arnold et al., 2007), most of the construction and mining industries follow certain forecasting methods to predict their future demand due to the long product lead time. As mentioned by (Armstrong, 2001; Jones & Twiss, 1978) forecasting is a decision making tool which is mainly concerned with predicting the future demand when there is an uncertainty.

The problems associated with the SRP method of forecasting are increased inventory level. Over estimating the forecast when there is an intermittent demand may lead to a serious threat of overstocking the products. On the other side, too low inventory levels can lead to lost business. Hence maintaining an optimal level of inventory by building safety stock is a challenging task (Mattsson & Jonsson, 2013).

According to (Krajewski et al., 2006), the ABC classification is the best practice to maintain the inventory level as it considers the economic value of the parts that has to be stocked. Because it does not cost much to have low cost components in stock, but the high cost components does cost much to have them in stock. Having excess inventory is like having the working capital on shelf without any transaction. One must be aware of the fact that it costs to stock, thus the inventory planning should be based on the concept of ABC classification.
But for the SRP to function well the sales input is the fundamental source. As mentioned by Wacker & Lummus (2002) sales input is the only source which one can rely upon to predict the future demands. But due to various factors such as the market condition and metal prices, the business cycle fluctuates and as a result the demand doesn’t remain stable and it leads to intermittent demand.

The problems due to the poor forecasting accuracy from inventory perspective are lack of availability of the materials or excess level of inventory. In order to reduce the forecast error, it is always essential to measure it. As there is always room for improvement, by measuring the forecast error one can possess the ability to know how precise they are in their estimation and also to measure the performance. The goal of measuring the error is to get an image of the randomness in the error i.e. if they are too low or high. By analyzing the forecast error it enables to improve the implemented forecast method and also build the minimum safety stock (Mattson & Jonsson, 2013).

2. How accurate is the forecasting done by the case company in the past years?

As mentioned by Mattson & Jonsson (2013), there should be an equilibrium between forecast and demand in order to maintain the inventory level. There are different techniques to calculate the forecast, in this case study the case company follows the SRP driven forecast. By studying the historical data, it is observed that there is a lot of variation in the demand pattern. It means the difference between predicted forecast and the actual demand is high. Also by looking at the actual demand pattern from the historical data, it is observed that there is a high level of fluctuation in the demand and also there are certain time periods with absolutely zero demand, even though there were certain forecast values for that time period. It results in large forecast error which directly affects the inventory levels. But looking into the case company’s product portfolio, all their products are highly customized depending on their application and hence there isn’t much commonality in their parts. This factor has a major impact on their inventory levels when there is an increased fluctuation in the demand.

In this thesis work, the forecasting study is done only for a few high cost commodities such as engines and frames. As mentioned, the case company produces highly customized products, there are nearly 100,000 different part number. By limiting just to the engines there are around 83 different engines that are used on their products. Other high cost unique parts have similar variety just like engines.

In order to measure the forecast accuracy of the existing system, a time series forecasting can be implemented. Silver et al., (1998) mentioned that in order to measure the performance it is always best to evaluate more than one forecast error measures. The different forecast accuracy measures such as mean square error, mean absolute deviation, mean absolute percentage error, etc. under the time series forecasting have been used in this thesis work. According to Krajewski et al., (2006) the naïve forecast is the most commonly used forecasting method by most of the business firms. Wherein, the previous day/month/year’s data helps the companies to predict the forecast better.

To measure the forecast accuracy, initially the forecast error has to be measured. In this project work, the available historical data is from 2013-2015. Both the predicted forecast and the actual demand are drafted into an excel sheet and the forecast error has been
calculated. The forecast error is the difference between forecast demand and the actual demand. It is calculated using the equation, \( E_t = D_t - F_t \) (Krajewski, et al., 2006)

Mattsson & Jonsson (2013) mentioned that if the error is positive or above zero then it is assumed to be a large error.

And further, various measures of forecast error have been calculated which includes:

- Cumulative forecast error: \( CFE = \sum E_t \)
- Average forecast error: \( \bar{E} = \frac{CFE}{n} \)
- Mean squared error: \( MSE = \frac{\sum E_t^2}{n} \)
- Standard deviation of error: \( \sigma = \sqrt{\frac{(E_t-\bar{E})^2}{n-1}} \)
- Mean absolute deviation: \( MAD = \frac{\sum |E_t|}{n} \)
- Mean absolute percentage error: \( MAPE = \frac{\sum \left(\frac{E_t}{D_t}\right)(100)}{n} \)

In this thesis work all the above forecast measures are calculated. First the forecast error was calculated and later the cumulative forecast error. Krajewski et al., (2006) mentioned that the cumulative forecast error is used to estimate the total forecast error while considering the data of a larger time period. And further, the average forecast error was calculated in order to calculate the mean absolute deviation of errors. According to Silver et al., (1981) the mean absolute deviation measures the magnitude of the forecast error and it is the most commonly used tool to measure the forecast accuracy because of its simplicity in the calculation. The mean squared error is also referred to as a forecast accuracy measuring tool and it estimates the variance from the mean average forecast error values (ibid).

Lumsden (2012) stated that standard deviation of error measures the variance from the mean value and it is also a measure of dispersion of the estimated forecast error values. MAPE is assumed to be a standard tool to measure the forecast accuracy, as it links the measured forecast error to the demand level (Krajewski et al., 2006). Chopra & Meindl (2001) mentioned that it is one of the best practices to measure the MAPE value in order to measure the forecast accuracy. But the MAPE value is not applicable when there is an intermittent demand, when the denominator is zero it gives infinite result, or it is undefined. For example, if the demand for a particular month was 0 and forecast was 5 and the calculation is done for an one year time period, then the MAPE value can be calculated as,

\[
MAPE = \frac{\sum \left(\frac{E_t}{D_t}\right)(100)}{n} = \frac{(5/0)(100)}{24} = 0
\]

Hence it is not suitable to use when there is a lumpy demand. In this thesis, the case company has a random demand pattern, so in the later stage a new key performance indicator known as mean absolute scaled error is used to measure the forecast accuracy. Hyndman & Koehler (2006) mentioned that it is a powerful tool to measure the forecast performance when there is a lumpy demand. It considers the absolute error value and calculated the standard deviation of the overall sample of forecast errors.

\[
MASE = \text{Mean}(\frac{E_t}{\frac{1}{n-1} \sum |Y_t - Y_{t-1}|})
\]

Here \( E_t \) is the actual forecast error in the numerator and it is divided by the average sample error. In the denominator, \( Y_t - Y_{t-1} \) is the difference of the sample error by referring to its previous forecasted value. It is more like a naïve forecast measure as it considers the preceding value. It is mostly preferred to measure the forecast accuracy when there is an intermittent demand (ibid).
In the hypothesis part of the thesis, the MASE is used as a comparison tool to measure the forecast accuracy of the existing system and with the Croston’s method of forecasting.

3. Which existing forecasting models are there for handling lumpy demands?

For any successful organization, the forecasting methods are chosen looking at the demand patterns or past historical data. Synetotos et al (2005) mentioned that selecting the appropriate forecast method relies on the nature of the demand. According to Krajewski et al., (2006) time series forecasting method uses the historical data to predict the forecast whenever there is a continuous demand for any product. By stressing on the word “continuous demand”, it can be analyzed that there are various types of demand patterns. They are Level, trend, cyclical, seasonal and random. Among these the random demand pattern is more complex; hence forecasting when there is a random demand is a tedious job. The random demand pattern refers to the continuous fluctuation in the demand values, or in other words an intermittent or lumpy demand.

Teunter & Duncan (2009) mentioned that, there are various forecasting methods available when it comes to intermittent or lumpy demand. The forecasting method includes, zero forecast method, exponential smoothening method, simple moving average, Bootstrapping, Croston’s method and few variations of Croston’s method. Among these simple moving average and exponential smoothing are the most commonly used but he also stressed on the fact that these two conventional methods are not satisfactory when we consider the inventory stocking decisions. The zero forecast method is the weakest of all since the predicted forecast values are zero all the time and it also affects the inventory management (ibid). Bootstrap method had certain drawbacks as it generated an artificial number without considering the previous demand value. Willemain et al (2004) also mentioned that although the researchers have made an attempt to develop some variations in the original Croston method, the results achieved were not satisfactory.

The authors have compared all the mentioned forecasting method by applying real time industrial data. Teunter & Duncan (2009), Willemain et al (2004) proved that the Croston’s (1972) method of forecasting gave better results when compared to the other existing methods.

4. What is the best alternate forecasting method that can be implemented to deal with the inventory issues?

Based on the literature study for this thesis work and by studying the existing forecasting system, a hypothesis tool has been built which is nothing but the Croston’s method. Most of the organizations assume that the nature of demand remains smooth or steady and hence when there is lumpiness in the demand their performance deteriorates. Olhager (2000) mentioned that to predict the forecast the historical data is a key consideration. Upon analyzing the historical data, there can be variation in the demand patterns. The observed patterns in demand can be level, cyclic, trend, seasonal and random (Krajewski et al., 2006). The author also mentioned that it is hard to predict the forecast when there is randomness in the demand pattern, because it directly affects the inventory due to under or over estimating the demand forecast. Due to these criteria, there exists an error in the forecast. Most of the
inventory strategies rely on demand forecasting in order to meet the material replenishment planning (Chatfield & Hayya 2007).

Based on the empirical results achieved by measuring the forecast error it was clear that there exists lumpiness in the demand. Thus, by exploring the built theories on forecasting, various researchers suggest that Croston’s method of forecasting is the best method to deal with lumpy demand (Willemain et al., 2004).

Willemain et al (2004) proved that Croston’s method is the most powerful forecast method when it comes to intermittent demand. He compared various other methods such as simple exponential smoothing, Bootstrap method to Croston’s method based on the lead time demand percentages. The author concluded that Croston’s method yields better accuracy and performance over the other methods. But Ghobbar & Friend (2003), stressed on the fact that the selection of forecasting method must also consider the degree of lumpiness factor.

According to Hyndman & Koehler (2006) the MASE is a standard tool to measure the forecast accuracy. He mentioned that to obtain a MASE value less than one is a challenge to achieve for any product organizations. By adopting the Croston’s method of forecasting it was noticed that the MASE value was significantly low when compared with that of the regular naive forecasting method. Hence it can be justified that Croston’s method is the best technique to deal with lumpy demand.

It is evident from this case study also that Croston’s method yields better forecasting accuracy (refer hypothesis section)
7. PROCESS BENCHMARKING

In this chapter three different internal benchmarks are done within the Atlas Copco group. It includes the benchmarking of forecasting process and finally the summary of all three companies is presented.

7.1 Atlas Copco Company A:

The forecasting cycle begins through the information gathering by sales and marketing department from the customer centers (CCs) across the globe. The information gathered is then delivered to the market analysis team which comprises of experts in market intelligence. They work on the gathered data and certain corrections are done by adding or removing of orders based on company's historical transactions and intuition to some extent. Usually around 20% of the orders are taken away which is referred to as sales optimization. Once this optimization process is finalized, the marketing manager passes the information further to initialize pre-strategic resource planning (Pre SRP).

The SRP review process for an upcoming year is done beforehand and then they are further split into quarters to fit into the financial calendar as well as to have intermediate targets. Once the SRP is finalized, it is followed by a freezing period preferably around 6 weeks where certain addition and deletion of orders is possible. Later on, the production team works on the SRP forecast values for around 4 weeks and a production plan is finalized. The production manager finalizes the material requirement plan (MRP) followed by the bill of materials (BOM) and then the orders are placed to the suppliers to obtain the parts. Company A observe a seasonal trend in their Q1 and Q2 business demand which suggests that there is always a ramp up in the demand trend, so it is safe for them to build the safety stock as the risk building the inventory is low for this particular period of the year. Whereas, in the last quarter Q4, there is low demand for their products as the demand follows a seasonal trend.

Sometimes, order intake can exceed the estimated demand, in such cases the order has to be placed earlier or else it can lead to increased product lead time. In such cases, the suppliers are paid extra to deliver it earlier than the regular part lead time. And then the product is delivered on to the customer within the estimated time period.

The Company A’s products are built in such a way that they have many common parts in their products. During the first two quarters they can afford to stock the low frequent parts such as engines, frames, rock drills etc. The frequently used parts of low/medium cost are usually stocked as it doesn’t cost much to have them in stock. Since there exists a commonality in their parts, it is utilized frequently without building any excess inventory and it keeps moving without building any tied up capital.

7.2 Atlas Copco Company B:

The forecasting process is initialized by obtaining information from around 24 CCs. This information is then transferred to an excel spreadsheet and then the market intelligence experts modify the data as the information gathered is still raw.

Once the required modifications are done, it is then approved by the regional business manager. The next step in this process is a mathematical approach where an analytically derived formula is applied to find the percentage of customers who will investing in buying new machines and also to find out how much percentage of those customers will probably
buy the machines manufactured by Company B. To proceed with the confirmed order, there should be at least 75 percentage chance for Company B to receive the order.

So, once the above mentioned calculation is done, a temporary schedule plan is prepared followed by a temporary material requirement plan. In order to make any addition/deletion on orders one has to get it approved by the production and planning managers. Based on these inputs, a Strategic Resource Planning is done and it goes into a couple of month long freezing period where further modifications are done on the order based on the past experience but it has to be approved by the global business manager. The changes made in the SRP level should be updated so that the production team can modify their plans in resource allocation and finally the orders are placed to the suppliers.

On an average 5 to 6 products are built per month, their main customers are from Africa and Russia. Due to the decreased volume in their products they have a better margin of error. Once the order is placed it takes about two months to produce the products for the customer. When there is no firm order and if the item to be purchased is above 10,000 USD then it has to be approved by the higher authority to place the order to their suppliers. Forecast is obtained from both local and regional markets. The forecasting method is purely subjective as a few customer centers are very aggressive and a few are conservative, therefore it is processed before it is finalized. The orders are reviewed on the weekly basis to improve the product lead time.

7.3 Atlas Copco Company C:

Company C builds drill rigs for construction and mining applications. There is not much variety in their product range. The forecasting is done on a global level by the marketing team and then the information is passed to Company C.

Due to the down turn in the business condition there is a huge reduction in their production output so now they have adopted the build-to-stock with Kanban strategy. Even though the forecast is done by gathering information from the customer centers, the forecast remains just as a reference. Two units are built which is considered as a base stock. It is a rolling process, due to the long lead time a safety stock of two units in inventory is maintained. In the country where they are based, the mining business is mostly dependent on the government policies. Due to some environmental issues, the government doesn’t give approval to the mining business because of hazards that have occurred in the recent years. Hence there is low potential demand in the local market which makes them hard to improve their business.

- **Summary of benchmarking**

By analyzing the forecasting processes from the above three different internal groups within Atlas Copco it is seen that they have their modification depending on the business performance. The reason for choosing these three internal companies within the Atlas Copco group are their similarity in the product portfolio, they face similar business challenges, and also the core values remains the same.

The Company A follows the SRP method of forecasting, but their business performance is good so they have high level of forecast accuracy. It is worth to mention that the company A has less variety in the product range and also there is lot of part commonality in their products. This is main reason for the company A to have better forecast accuracy.
Just like the case company, even the Company B follows SRP method of forecasting. The Company B still have the better forecast accuracy, upon studying their forecast process it is observed that they follow certain probability calculation in order to confirm the possibility of receiving an order from the customers. This step acts as an optimization step to start with, for the whole process. Also, they are extremely careful about the high cost orders, whenever they receive an order of more than 10,000 USD they take it further and get an approval from the higher authority to confirm the order before placing order to their suppliers. This step acts as a safety check in order to avoid high inventory level.

Coming to the Company C, their forecasting process is pretty simple thanks to the down-turn in market conditions, so they have adopted a build-to-stock strategy in order to avoid inventory pileups. It is suitable for company C to adopt this strategy as their product range is not that wide. Due to this fact, it makes them easy to build the required safety stock. Whenever there is an increased customer order, it takes longer lead times as they have implemented build-to-stock strategy. This method is beneficial as it avoids building inventory levels and achieves better forecast performance. At the same time, it is a cautious approach during tough business conditions and not a customer-centric strategy.
8. CONCLUSION

In this chapter the summary of thesis work is presented. It includes the findings from the empirical study, benchmarking and the hypothesis result.

The case company in this study follows SRP driven forecasting method. Since the past few years, the mining business has considerably gone down due to the market conditions such as low metal price. Looking at the demand patterns of the case company, one can see that there is lumpiness in the demand due to markets heading downwards as aforementioned. As a result, the task of inventory management gets too tedious. The customer satisfaction is a top priority for almost all the product and service organization in-terms of delivering products/services in time. On the other hand, having the excess inventory is not economical as it costs an arm and a leg to have the high cost commodities in stock. Hence, having an optimal inventory level is important for the company to sustain growth and be profitable.

After thoroughly studying the existing forecast system, clearly, SRP driven forecasting method does not take historical demand data into account. Instead, resources are spent on market analysis and current trends in order to optimize the forecasted values. Some degree of uncertainty is always involved using the above method, so predicting the future demand is a trade-off when the market trend fluctuates.

Therefore, to tackle lumpy demand problems, a hypothesis tool (namely the Croston’s method) has been built in this project work. A KPI known as MASE is used as the comparison parameter. The MASE value calculated after inserting raw SRP forecasted demand and actual demand is higher than the respective MASE value calculated using the Croston’s mathematical equations. So, this thesis investigation proves that Croston’s method of forecasting reduces error margins when there is a lumpy demand. As a result, the forecast accuracy improves considerably which reflects the optimized inventory levels. Croston’s method can be concluded as a best practice when there is a lumpy or intermittent demand.

Why MASE is chosen over MAPE? Using the time series method, various forecast error measures were calculated such as CFE, MSE, SDE, MAD and MAPE. The errors were calculated using the past few years forecast and demand data of the case company. Many authors have stated that MAPE is the standard tool to measure the forecast accuracy but in this thesis the case company has an intermittent demand pattern. So MAPE is not suitable when there is a lumpy demand as the demand values are zero for certain periods of time. Hence, it is not used in the following hypothesis instead the MASE value is calculated, which is ideally preferred to measure forecast accuracy when there is an intermittent demand.

Croston’s method is not suitable when the forecasting has to be done for a newly launched product since there will be no availability of historical data. Apart from this, as mentioned earlier, this forecasting method is totally dependent on the nature of the demand. If there is a ramp up in the business i.e. if the business improves and if it follows the seasonal trend then definitely the existing forecasting method SRP will still yield better results.
To talk about the findings from the benchmarking companies in a nutshell, Company A has really good forecast accuracy and it is because of their low product range and commonality in their parts. As the forecast accuracy and business performance is really good there will not be any necessity to implement the Croston’s method. Considering Company B, a lower product mix has made them to improve the forecast accuracy which means there will be reduced risk of building inventory. But the hypothesis tool can be suggested to Company B as their product portfolio and business challenge match very closely with the case company. Finally considering Company C, their build-to-stock strategy cannot be implemented by the case company as their products have long lead time. Croston’s method might not be of much to Company C because of their manufacturing strategy. If the business condition improves then it can be suggested as an option. On a general note, the findings from the benchmarking were really valuable, as the benchmarked companies have a different strategy which makes them to have different approaches. The benchmarking process is also a good tool to improve an organization’s forecasting process as it can find best practices followed in the contemporary industries to improve continuously. Both internal (sister divisions) and external benchmarking on forecasting processes within an organization with similar product portfolio is advised.

On a final note, it can be concluded that the case company can improve the forecast accuracy by having commonality in their parts using modular design principles, discontinuing the low demand products, and having only the most demanded products in the list. The case company can reduce the inventory level by building on order, reconfirm and approval of purchased parts from higher authority when there is no firm customer order. Hopefully, the thesis findings will help the case company to improve their forecast accuracy during unfavorable market conditions by adopting the hypothesis tool built in this thesis.

9. FUTURE WORK

1. Croston’s method can be applied to medium cost components as well to reduce the inventory levels.
2. External benchmarking could be done with like-minded companies who have similar product portfolio and face similar business challenges.
3. Optimization software SO99+ could be implemented.
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11. APPENDICES

A. Interview questions for Benchmarking

1. How the forecast process works?
2. What is the current forecasting method based on?
3. What are the various sources to gather the market forecast?
4. How often the data is gathered from the customer centers?
5. How accurate is the information that has been gathered from the customer centers?
6. How often the information is gathered from the customer centers?
7. To what extent the sales data are modified?
8. How the forecast values are modified in the later stages before finalizing it?
9. Is there any margin of forecast error?
10. What happens when the forecast values are incorrect?
11. Is the forecasting done globally? Or just for regions?
12. What are the factors that affect the customers buying decision?
13. On what perspective do you look at the business market?
14. How often do you review the forecast values?
15. How frequently the meetings are conducted with the suppliers and customers?
16. To what extent the government tenders are considered?
17. If there is a possibility to improve the current process, then is there any suggested improvement that you can think of?

B. The forecast error measures for engines

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D. The forecast accuracy comparison of SRP forecast and with the Croston’s forecast

Engines: MASE value comparison of SRP forecast v/s Croston forecast

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Example 2:

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**Frames**: MASE value comparison of SRP forecast v/s Croston forecast

### Example 3

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### Example 4