Classification of supplied components

Kristofer Sveger and Kristin Svensson

Preface

This thesis was written as the final part of our Master of Science degrees in Mechanical Engineering and Industrial Engineering & Management at Lund University, Sweden, during the spring of 2014. The project was performed in collaboration with The Company, with the purpose to suggest a model for classification of supplied components, which challenges the model currently used at the company.

The past five months have been a challenging and interesting period, where we have learned a lot and have had the possibility to develop and demonstrate the knowledge provided during our previous courses. All personnel we have met during the project have been of great help, providing us with data and information about the processes at The Company. We would like to send a special thank to our supervisors at The Company, whom have supported us during the whole project.

We would also like to thank our supervisor at the university, Eva Berg, at the division of Engineering Logistics, for her insightful comments and support during the project. In addition, we would like to thank the benchmarked companies for their willingness to share their experience with us.

Finally, we would like to thank family and friends, for all the support and joy they brought us during these five years of studies towards our degrees in Mechanical Engineering and Industrial Engineering & Management. You have been of great importance to us!

Lund, June 2014

_____   _____

Kristofer Sveger   Kristin Svensson

Abstract

Title:	Classification of supplied components
Authors:	Kristofer Sveger and Kristin Svensson
Supervisors:	Eva Berg, Department of Industrial Management and Logistics, Lund University, Sweden
	Director Supply Chain Management, The Company, Sweden
	Supply Chain Developer, The Company, Sweden
Examiner:	Jan Olhager, Professor, Department of Industrial Management and Logistics, Lund University, Sweden
Background:	The electronic manufacturing company The Company implemented a new model for ABC classification of supplied components about 4-5 years ago. Today, they want to challenge this model and evaluate if they have been using the correct parameters, or if improvement can be made. They wish for a new model that is based on the theory in field, to make a comparison with the existing model. The purpose with the ABC classification is to manage uncertainties from suppliers, in terms of delivered quality, variation in lead times and inventory errors.
Purpose:	The purpose of this thesis is to suggest a method for classification of supplied components at The Company that challenges the model currently used, and give recommendations on how to use it. The new model should be applicable to all The Company's market segments.
Problem definition:	Which parameters are suitable to use to classify supplied components at The Company?
	How should the parameters be combined for classification?

How many classes are reasonable to use and how should these classes be divided in order for the model to be useful?

Methodology: This thesis has been performed with a systems approach, to capture the holistic view of classification models. The abductive research method is used with both qualitative and quantitative data collection through interviews, benchmarking and data from ERP system. The authors have used an iterative process between theory and practice.

Results: This thesis has concluded that volume value, supplier lead time deviation and unit cost are suitable parameters to use for classification at The Company, together with the Ng-method. The recommendation is to continue working with ten classes, and use the 80-20 rule as guideline to divide the components.

Conclusions: The following conclusions about classification could be drawn from this thesis:

- Both single criterion and multiple criteria methods exist and are further developed to give better result and be more user friendly.
- Input parameters could be of both qualitative and quantitative nature, where the former in general requires more work from the user.
- There is no clear theoretical guidelines of how many classes to use, and it should depend on what is possible from a management perspective.
- The difference in number of components in each class is often divided according to the 80-20 rule or according to experience.

Keywords: ABC classification, supply, inventory management, purchase classification

Sammanfattning

Titel:	Klassificering av inköpta komponenter
Författare:	Kristofer Sveger och Kristin Svensson
Handledare:	Eva Berg, Institutionen för teknisk logistik och produktionsekonomi, Lunds Universitet, Sverige
	Director Supply Chain Management, The Company, Sweden
	Supply Chain Developer, The Company, Sweden
Examinator:	Jan Olhager, Professor, Institutionen för teknisk logistik och produktionsekonomi, Lunds Universitet, Sverige
Bakgrund:	Elektroniktillverkaren The Company implementerade för 4-5 år sedan en ABC-klassificeringsmodell för klassificering av de komponenter som de köper in. Nu vill företaget utmana den nuvarande modellen och utvärdera om de använder korrekta parametrar för klassificering, för att undersöka om det finns möjlighet till förbättring. Därför efterfrågar The Company en ny modell som baseras på den teoretiska kunskap som finns inom området för att kunna göra en jämförelse med den befintliga modellen. Syftet med ABC klassificering är att hantera osäkerheter från leverantörer vad gäller leveranskvalitet, ledtidsvariationer och saldofel.
Syfte:	Syfte med examensarbetet är att föreslå en metod för att klassificera de komponenter som The Company köper in, och ge rekommendationer för hur denna kan användas. Modellen skall vara applicerbar inom alla The Company's marknadssegment och utmana den nuvarande modellen.
Problemdefinition:	Vilka parametrar är lämpliga att använda för att klassificera de komponenter som köps in?
	Hur skall parametrarna kombineras för klassificering?

Hur många klasser är rimligt att använda och hur skall dessa klasser delas in för att modellen ska vara användbar?

Metod: Detta examensarbete har utförts med ett holistiskt perspektiv på klassificeringsmetoder. Ett abduktivt arbetssätt har applicerats på både kvantitativ och kvalitativ dataanalys genom intervjuer, benchmarking och data från företagets ERP-system. Författarna har använt sig av en iterativ process mellan teori och praktik.

Resultat: Volymvärde, leverantörers ledtidsdifferens och artikelpris är de tre parametrar som The Company rekommenderas att använda för klassificering tillsammans med Ng-metoden. Vidare är rekommendationen att The Company ska fortsätta arbeta med tio klasser och att utgå ifrån 80-20 regeln vid klassindelning.

Slutsats: Följande slutsatser om klassificering har dragits:

–   Det finns klassificeringsmetoder både med en och flera kriterier. Dessa metoder har utvecklats för att skapa en bättre klassindelning och vara mer användarvänliga.
–   De använda parametrarna kan både vara kvalitativa och kvantitativa, där de förstnämnda generellt sätt kräver mer arbete av användaren.
–   Det finns inga tydliga teoretiska riktlinjer för hur många klasser som ska användas. Klassindelningen beror oftast på vad som är möjligt i ett managementperspektiv.
–   Antalet artiklar i varje klass bestäms oftast efter 80-20-regeln eller efter tidigare erfarenheter.

Nyckelord: ABC-klassificering, supply, försörjningsstrategi, lagerstyrning, inköpsklassificering

Definitions

Classification criterion is a *parameter* used in a classification method.

Classification model includes a *classification method*, a specified number of *classification criteria* and how to divide *components* into classes.

Component is a part used in production of a product and can also be called *part*, *SKU* or *item*.

Enterprise Resource Planning system (ERP-system) is a business management software that companies use to control their business. The system provides information such as financial information and production planning (Axsäter, 2006, p. 212).

Inventory level is defined as (Axsäter, 2006, p. 46):

$$Inventory\ level = stock\ on\ hand - backorders$$

Inventory position is defined as (Axsäter, 2006, p. 46):

$$Inventory\ position = stock\ on\ hand + outstanding\ orders - backorders$$

Volume value is defined as the *unit cost* multiplied with the *annual demand* and can also be called *demand value*, or *annual dollar usage*.

x

Table of content

List of figures

List of tables

1 Introduction

This chapter is an introduction to the master thesis and the case company. It describes the background of the studied field, the purpose, research questions, scope and delimitations. In addition to this, the target group and structure of the thesis are presented.

1.1 Background

This master thesis has been conducted together with The Company in the field of supplied components classification. This section will introduce the reader to the research topic and the case company.

1.1.1 Classification

With increasing globalization in the manufacturing sector, the supplier network has increased in complexity to meet customer needs (Van Weele, 2009, p. 16). The increased number of suppliers has meant that it has become even more important for companies to manage their suppliers in an efficient way, by developing effective inventory control policies.

It is common for manufacturing companies, whom often works with thousands of articles, to classify the components or the component suppliers, in order to streamline the organization and the management of inventories (Martin & Stanford, 2007). The classification allows the company to have control over all components and divide them into various groups assigned to different strategies. The methodology implies grouping and classifying articles by various parameters. Differentiation of components is important for the allocation of resources in the company e.g. capital and capacity utilization.

Generally, a small fraction of a manufacturing company's purchased items represent a large fraction of expeditors (Hopp & Spearman, 2011). To spend the same amount of purchasing activities in procurement of all items is obviously irrational. For components that represent high purchase prices and are purchased in large volumes, it may be appropriate to conduct a proper evaluation of alternative suppliers to be able to negotiate the best possible conditions (Van Weele, 2009, p. 25).

One of the most widely used models is the ABC classification (Martin & Stanford, 2007). During the past 20 years has this method been developed to include more than one criterion. The goal with the ABC classification is to manage uncertainties from suppliers, in terms of delivered quality, variation in lead times and inventory

errors. The original method divides the inventory items according to the parameter volume value.

The number of criteria used to manage inventory varies depending on the type of business/industry (Flores, et al., 1992). To obtain strong results in the classification of suppliers/components, it is important to choose the classification criteria with care and not only work with the annual dollar usage (Flores, et al., 1992).

A reason for classifying components is to manage safety stock, which is used to hedge against unpredictable fluctuations in demand, so that shortages preferably will not occur. The use of safety stock involves tied up capital and inventory costs. Therefore, classification is an effective approach for differentiating service levels so that articles, for which shortages have a significant impact, are allowed a greater proportion of the capital invested in safety stock than articles for which the impact is not as significant.

1.1.2 Company description
The Company is a global electronic manufacturing company, with head office in Sweden. The company operates within the electronic business. Their customers are mainly other global companies in Europe (The Company, 2012).

With operations in Europe, the United States and China it is possible for The Company to meet their customers' needs, both in terms of local presence and competitive mass production. The production sites can together handle both high volume production in the maturity phase of the product lifecycle as well as low volume in the beginning and end of the product lifecycle (The Company, 2012).

1.2 Purpose and research questions
About 4-5 years ago, The Company implemented an Excel-model for classification of supplied components. Today, they want to challenge this model and evaluate if they are using the correct criteria, and benchmark them with companies within similar industries. The new model should be based on the theory in the field.

The purpose of this thesis is to suggest a method for classification of supplied components at The Company that challenges the model currently used, and give recommendations on how to use it. The new model should be applicable to all The Company's market segments.

The purpose causes the following research questions:

- Which parameters are suitable to use to classify supplied components at The Company? (R1)
- How should the parameters be combined for classification? (R2)
- How many classes are reasonable to use and how should these classes be divided in order for the model to be useful? (R3)

The suggestion of a model will include the input parameters, which method to use for combining them and a discussion around the output classes. An illustration of the aim of the thesis is showed in Figure 1.1.

Input
Attribute set (x)

Classification model

Output
Class label (y)
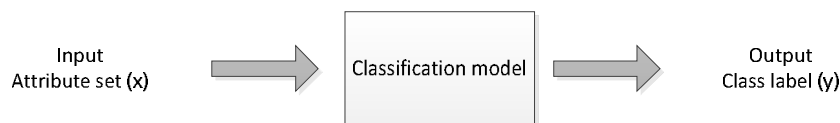
Figure 1.1 Aim of the master thesis

1.3 Scope and delimitations

This thesis will focus on supplied components and their characteristics at The Company and will not address other classification situations in the company's supply chain e.g. customers, segments or markets. The authors will deliver a new proposal on how a classification model should be designed, but a new working Excel-model will not be performed. This is due to time limitations and the scope of the thesis.

Another limitation, which will affect the final result, is the quality of the gathered data. Some information is not easy to obtain and would need more time than the project allows for to acquire. Other data is available, but a bit older than desired, and might therefore not be subject for an accurate analysis.

The project will not take into consideration the forecasting procedure or production scheduling, i.e. view the production demand as fixed. A schematic view of the delimitation is illustrated in Figure 1.2.

Delimitation of thesis

Suppliers

Internal supply chain

Customers
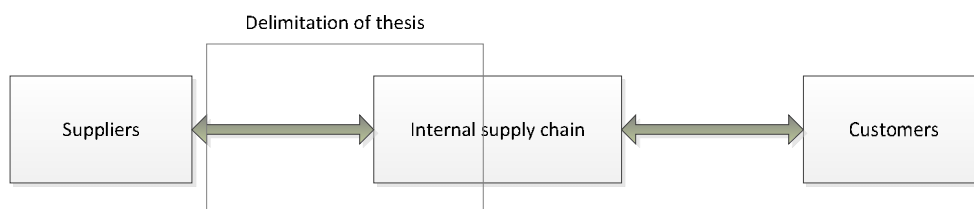
Figure 1.2 Delimitation of the master thesis

1.4 Target group

The target group of this thesis is primarily logistic managers, supply chain managers and other employees at The Company that are connected to the supply of components and purchasing. Additionally, the thesis can also be of interest to academics in supply chain management and logistics, or other people with interest in logistics.

The thesis can also be used as a starting point for the development of a new classification model, or to redesign the existing model for supplied components at The Company.

1.5 Structure of thesis

The thesis is divided into eight parts as illustrated in Figure 1.3, and will be introduced below.
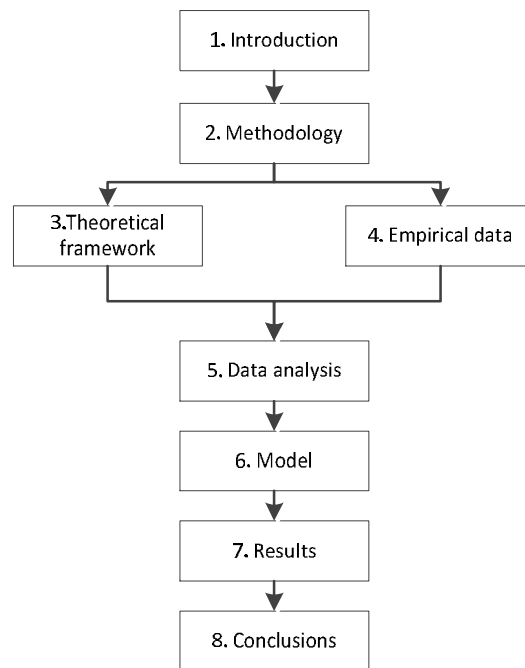
Figure 1.3 Schematic view of thesis

Chapter 1, *Introduction*, presents the background and purpose of the thesis, a problem discussion with related research questions and a short company presentation.

Chapter 2, *Methodology*, presents the chosen approach that is used for this research as well as a discussion about the approach. The research design for the thesis is also presented, and also the trustworthiness of the thesis is discussed.

Chapter 3, *Theoretical framework*, presents the basis of underlying analysis. It is introducing the reader into different subjects and methods that are relevant in this thesis, such as theory regarding classification methods, parameters and inventory control.

Chapter 4, *Empirical data*, constitutes together with the previous chapter a base for analysis. Information regarding processes within the company and supplied components are presented. Information collected through the benchmark interviews is also presented.

Chapter 5, *Data analysis*, presents the analysis and conclusions of the gathered empirical data. The purpose is to find parameters that are of interest for the classification of supplied components at The Company.

Chapter 6, *Model*, presents the suggested method for classification of supplied components and gives recommendations on how to use it. The parameters that are identified as suitable to use in the model, the number of classes and the number of articles in each class are also discussed.

Chapter 7, *Results*, presents the results and findings of the thesis. The recommended model is presented together with the validation of the model and the assumptions that are made during the development of the model.

Chapter 8, *Conclusions*, presents the conclusions that can be drawn from this thesis. The fulfillment of purpose of the thesis is discussed as well as recommendations to The Company for further research within this field.

2 Methodology

This chapter presents the methodology used in the thesis, which includes the scientific approach, research method, research strategy and design as well as the data collection and data analysis methods. At last the trustworthiness of the report will be discussed.

2.1 Scientific approach

The ambition for a research project could be explained as steps in a stair, where the previous steps have to be fulfilled to enter the next (Nilsson, 2014). The stages are often called exploratory, descriptive, explanatory, predictive, normative, implementative and at last evaluative, see Figure 2.1. The ambition for this thesis is set to normative, since the purpose is to find a "To be"-state, i.e. a model suitable for classification at The Company.
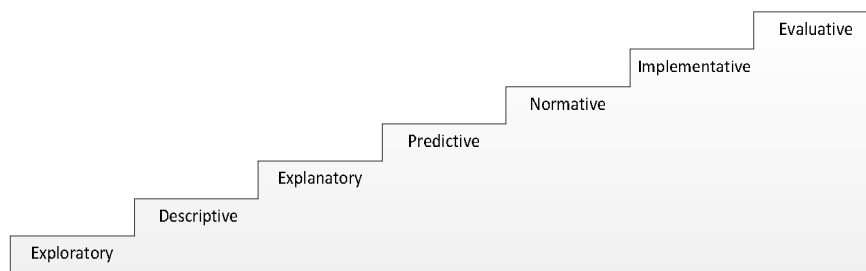
Figure 2.1 The ambition stair

To fully understand a researcher's work, the audience must know the researchers scientific approach. Different researchers interpret the surroundings in various ways, with different assumptions. This results in a slightly different view of scientific work. Another reason for presenting the methodological approach is to ensure the audience that no approach is taken for granted and give a better understanding of previously research in the field (Gammelgaard, 2004).

One way to separate approaches for business studies is presented by Arbnor and Bjerke (2008), whom have formulated a methodological framework with three major approaches. The analytical approach assumes an objective reality and aims for a cause-effect relationship. The problem can be divided into sub-problems, to find the solution one part at a time. The findings should be general and the researcher should stay outside and not interact with the examined object. The systems approach on the other hand is based on systems theory and a more holistic view. The findings are valid for the examined case, and are closely

7

connected to that context. Finally, the actors approach assumes the reality is not objective, but result of social constructions (Gammelgaard, 2004). The researcher is a part of the process, and should interact with the studied objects.

Arbnor and Bjerke (2008, p. 11) argue that the chosen method should fit both the problem and the presumptions held by the researcher. The approach chosen for this thesis is therefore systems approach. The main idea with a classification model is to prioritize among the classified items, whether if it is components, suppliers or something else. This means that it is seen as a system, since each item is influenced by all other items. For example could an item be seen as the most important and receive most attention, but this would change if other even more important items would be included in the system. For this reason is the analytical approach not a suitable choice, since the problem not could be split into subsets. Neither the actors approach is suitable since the purpose of this thesis is not to investigate individuals' behaviour in the system. Although this could have some minor influence for the end result, people and their interactions would not be the primary unit of analysis.

2.2 Research method
To achieve the objectives of the study it is important to select an appropriate research method that influences how the research is conducted. Research methods combine empirical observations with theory in different ways, and are therefore used in different contexts depending on the purpose. The most commonly used methods are inductive and deductive research (Kovács & Spens, 2005).

An inductive method starts with real-life observations that are analyzed and theoretical conclusions are drawn. These can later be applied in future situations. The method is usually used in contexts where there is lack of theory in field. In contrast to the inductive method, the deductive method starts in theory and different hypothesis are formulated from the theory. In a second step the hypotheses are either accepted or rejected.

A third alternative method is abductive (Kovács & Spens, 2005), illustrated in Figure 2.2. This method is a combination of the inductive and deductive approach. Both existing theories and empirical data are used to draw conclusions and find new connections. As in the case of the inductive method, the abductive research starts with a real-life observation where problems or deviations are identified. Since researchers often have theoretical knowledge in the field an initial

theoretical step can be introduced before the observation. The process develops thereafter to an iterative process, which continues through additional empirical observations where further knowledge is added until an adequate theoretic framework is established. The abductive research method ends with a hypothesis or a proposition.

The abductive research process
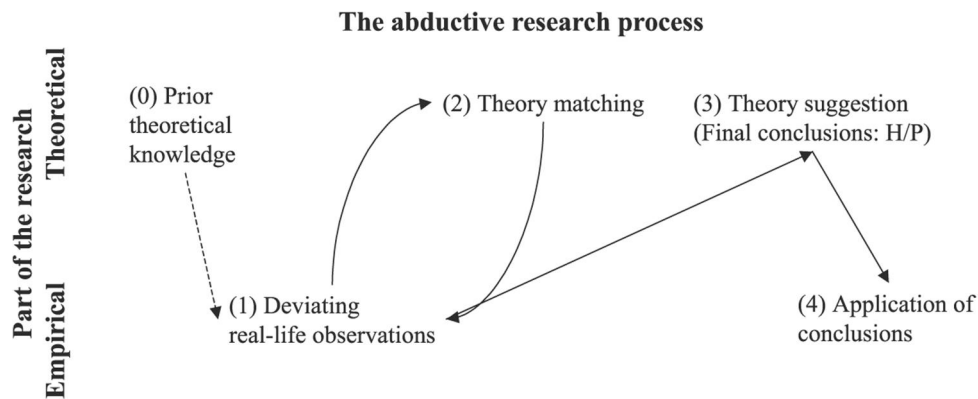
Figure 2.2 Illustration of the abductive research process (Kovács & Spens, 2005)

For this thesis an abductive research method is used due to the fact that the problem is already identified at The Company, and the project will result in a suggestion for how to classify supplied components. The deductive method starts in theory where a hypothesis is formulated, and the inductive research starts with a real-life observation, which is analyzed and theoretical conclusions are drawn, but it lacks the iterative process between observations and theory. Because of this, these two methods are not useful for the direction of this thesis. With an iterative process, theoretical conclusion is developed by stepwise increased knowledge about classification and the company's processes.

2.3 Research strategy

A number of different research strategies are defined in the literature; survey, experiment, case study and action research. These are all relevant when performing a master thesis (Höst, et al., 2006). A survey is used to describe the current state of the studied object, or phenomenon. Experiment is a comparative strategy of two or more objects with the purpose to isolate and manipulate factors in order to find causality and to explain the reason for certain phenomena. Both survey and experiment are based on a fixed research design, which should not be changed. Case studies are more in-depth and more detailed studies of one, or several cases in a contemporary context. The structure of a case study is

flexible, which makes it possible to adjust research direction as the study progresses. Action research is a version of case studies. It is more flexible and has a methodology that can be modified if the conditions change. It is suitable when the problem should be solved at the same time as it is studied. The method follows the Shewhart-cycle, plan-do-check-act, and it is the method used for this thesis. Table 2.1 summarizes the above mentioned research strategies.

Table 2.1 Summary of research strategies (Höst, et al., 2006, p. 43)

Research strategi	Main objective	Design
Survey	Descriptive	Fix
Experiment	Expositive	Fix
Case	Explorative	Flexible
Action research	Problem solving	Flexible

2.4 Research design

This project has two deliverables. One is to suggest a model for classification of supplied components at The Company, and the other, a thesis describing methodology, theory and the result of the project.

The research is divided into two parts; pre-study and action research. The pre-study is illustrated in Figure 2.3 and begins with exploratory interviews at The Company´s office. The purpose of this part is to discuss the company, the electronic manufacturing business, and different ideas about the problem. The obtained information is then used as the base for adjustment of the problem description, objectives, delimitation and scope. These two steps are followed by a literature review in parallel with the selection of research method, in order to solve the problem.
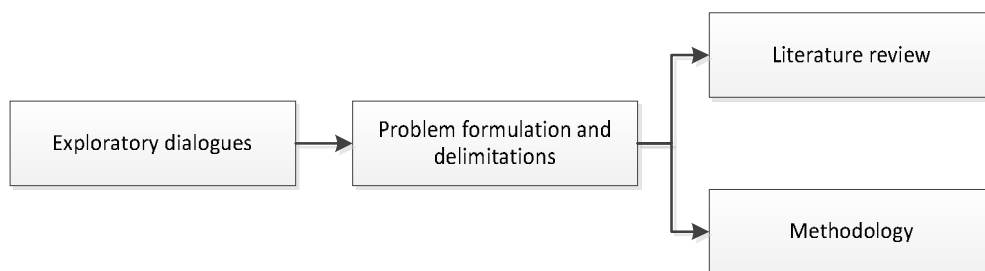
Figure 2.3 Research design for the pre-study

The pre-study part is followed by the above described abductive research method, which includes an iterative process between theoretical knowledge and empirical observations. Empirical observations are conducted by using interviews at The Company and the benchmark companies as well as data from the company´s ERP-system. The research design for the thesis is illustrated in Figure 2.4.
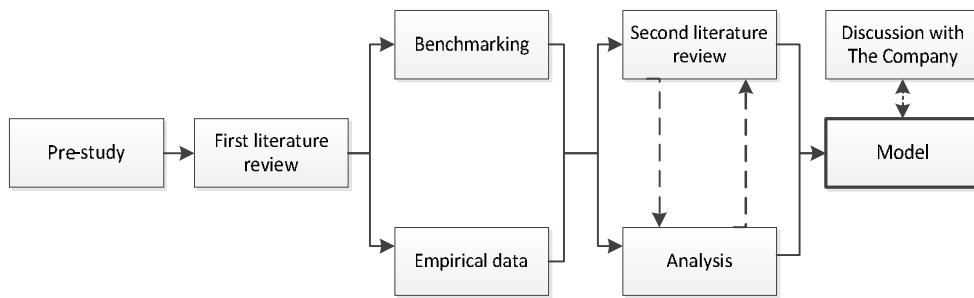
Figure 2.4 Stages of research in the thesis

2.5　Data collection

In order to construct a model for classification, a critical step is to gather relevant data to base the conclusions on. The relevant data for this master thesis are collected from interviews with personnel at The Company, benchmarking interviews, literature studies, the ERP-system at the company and other company documents.

2.5.1　Primary and secondary data

There are two main groups of data, primary and secondary data (Höst, et al., 2006). Primary data is unique for a project and is collected and analyzed specifically for the research questions, while secondary data is collected and analyzed for another purpose. Therefore it is important to review the source and the content critically, to control if it is objective or subjective.

For this thesis, primary data is collected by interviews and secondary data is collected from the company's ERP-system and from literature about classification and inventory management.

2.5.2　Quantitative and qualitative data

There are two different ways to collect data; quantitative and qualitative (Höst, et al., 2006). Qualitative data research is in the form of words, and cannot be measured numerically. It requires special methods of categorization and analysis.

Quantitative data research can be measured, grouped and analyzed with statistical and numerical methods. For this thesis, both quantitative and qualitative data will be gathered.

2.5.3 Exploratory interview

There are three main categories of interviews; structured, semi-structured and none-structured (Höst, et al., 2006). The structured interview follows a pre-written questionnaire and only allows for clarification of the question, while the none-structured also follows a questionnaire, but allows the interviewer to reformulate the questions and ask them in any sequence. The semi-structured interview is basically a structured interview, but it gives the interviewer the opportunity to ask relevant follow-up questions depending on the answers.

To understand problems within the electronic manufacturing industry, and The Company's processes that are associated with the supply chain management, initial interviews are held with personnel responsible for supply at the head office and at one of the company's production plants. In order to provide a broad overview and to give an opportunity for the interviewee to describe their own experiences and observation, the interviews are none-structured. The none-structured interviews are followed by semi-structured interviews, to focus more on the specific problem. The objective of the semi-structured interviews is to understand how the users use the current classification model. A second objective is to discuss their thoughts about how they use the model and the outcome of it.

2.5.4 First literature review

The first literature review is made in parallel with the exploratory interviews. The purpose of the first literature review is to establish a theoretical framework that focuses on different classification methods and on capital that is tied up in inventory. The databases used for searching and selection of articles are Science Direct, EMERALD, Elsevier, EBSCO Host, ISI Web of Science and Google Scholar. These are chosen since they are renowned databases with a substantial selection of reliable academic articles in the field.

The literature review is based on journal articles and books that are related to supply chain management and inventory management. The journal articles are mainly selected from well-known journals that has been referred to a several times or that refers to other well-known articles. If this is not possible recently published articles are selected. It is also desirable to capture the views from

different authors. From the search result, 20 articles and books is selected and used, based on these criteria.

The literature review on classification methods includes both the original model that was developed during 1950´s and more recently developed methods. In addition to the theoretical literature studies regarding classification, supplementary studies are conducted to understand the business which The Company belongs to, and which classification parameters that may be important to use.

2.5.5 Benchmarking

In addition to empirical studies at The Company, an industry benchmark is made. The purpose of the benchmark is to complement the theoretical framework from the literature review.

Benchmarking is a comparison of processes in one organization to a similar organization. It can be divided into four different types; product benchmarking, functional or process benchmarking, best practices benchmarking and strategic benchmarking (Nahmias, 2009, p. 680).

Product benchmarking focuses on the design and construction of a competitor's product, by carefully examine the same. Functional benchmarking focuses on the processes in the company rather than the company's products e.g. assembly, product development and logistics. Best practices benchmarking focuses on management practice factors, such as work environment and incentives for employees, in companies that are best in its area. Finally, strategic benchmarking refers to the strategic activities of the company and is a result of other benchmarking studies.

For this thesis, functional benchmarking is used as it focuses on processes within the company. The benchmarking is of qualitative character and will be used in order to gain knowledge and understanding of how other companies work with classification of their supplied components or their suppliers. Companies for benchmarking are selected due to their similarity in business and processes. All interviewed companies will be anonymous in this report.

2.5.6 Second literature review

In connection with the analysis of data collected from the company´s ERP-system a second literature review is made to acquire more knowledge, which is needed

to develop the model. The second literature review focuses on specific methods that are applicable on findings from the data. The search is conducted in a similar way as the first literature review, and the literature in this phase is mainly journal articles that provide more specific knowledge, which can be hard to find in books.

2.6 Data analysis

In order to utilize the gathered information, the data is analyzed using different techniques. The procedure for selecting criteria and classification method are described in this section.

2.6.1 Data mining

Yin et al. (2011) describes data mining as a process of discovering valuable information from observational data sets. It brings together techniques from different disciplines, such as statistics, optimization theory, pattern recognition and visualization. It is used to discover patterns and relations in the collected data.

The data mining process consists of three steps (Gorunescu, 2011, p. 7). The first step, exploring the data, could involve data cleansing, selection of subset or data transformation. Then, in step two, the model is built, which implies a selection of an appropriate model and secure the validation of the outcome. The last step is to apply the model to the gathered data, in order to discover information.

2.6.2 Selection of parameters

To be able to answer the first research question, regarding criteria, possible parameters affecting the classification are identified in a number of different ways, see Section 2.5. These are grouped together into major categories in an Ishikawa diagram.

Ishikawa diagram is also known as Cause and effect diagram or Fishbone diagram, since it looks similar to a fish skeleton. The tool helps to organize factors and causes and relate them to the main problem. It visualizes the information in the form of a spine, to which main causes, with minor causes attached, are connected (Bergman & Klefsjö, 2012, pp. 242-246).

2.6.3 Selection of classification method

To answer the second research question, different classification methods are gathered from the literature. These are then evaluated by how suitable they are in The Company's situation. This is done in discussion with the company, to

ensure that no incorrect admissions are made, and the outcome is some possible methods to use together with the selected parameters.

When a suggestion for the new model is developed, all components will be classified and employees at The Company will examine the result in a seminar at the end of the working period. This is done to discover if important aspects have been neglected and to ensure a reliable result.

2.7 Validity and reliability

All research methods have strength and weaknesses, which have to be taken into consideration. The used method affects the quality of the study, and should therefore be chosen carefully. The quality and trustworthiness of a study could be measured in many different ways, but Yin (2009) suggests four tests that are commonly used; construct validity, internal validity, external validity and reliability.

Validity could be described as the connection between the object to examine and what is actually measured. For the construct validity, this means identifying proper measure for what is actually studied. It should therefore be especially emphasized in the data collection phase, to ensure that the appropriate objects are studied. The tactic to handle it is to gather data from multiple data sources, to maintain a chain of evidence and link the observations together and finally to have key informants review drafts of the study report.

To ensure the construct validity in this thesis, all of the tactics mentioned above is used. Different people have been interviewed regarding the same topic and written data, e.g. the annual report, have been used for control when available. Reviewers are used in terms of supervisor and two opponents, which review this thesis as a part of their examination, to ensure high quality. Finally, the three supervisors who follow the project along the way secure the chain of evidence, e.g. the red thread.

Internal validity deals with the internal relationships in the study, and secures that causality exists and that incorrect conclusions are avoided. The tactic to handle this is to do pattern matching and address rival explanations. Since the purpose with this thesis not is to explain causal relationship is this aspect of the validity not emphasized.

External validity focuses on if the findings can be applicable to other situations apart from the certain case that is studied, i.e. if the result could be generalized. Since the purpose is to suggest a model that can be used at The Company, and this model should be suitable even if components and product range changes, the model could also be useful for other companies in similar industry under equivalent conditions. The model should also be applicable to all The Company´s sites, regardless market segment, requiring it to be adequately generic.

Finally, reliability refers to the reliability of the data collection and analysis with regard to random variations. During the theory building phase is it important to ensuring the reliability of information. To ensure correct theoretical understanding, the information is collected from recognized academic journals and books. Articles have been chosen with respect to how many times they have been cited, to ensure a high quality, as motioned in Section 2.5.4. The development of a model will be built on the analysis of the empirical data and theoretical knowledge. This means that it is important to have validity in the analysis phase to create a functional model.

Regarding the benchmarking, all interviewees will be sent the interview notes to make sure that no misunderstandings were made. They are later on also sent the text intended for the report, to ensure the accuracy.

3 Theoretical framework

This chapter is a review of the theory, which is relevant for the analysis of this thesis. It contains theory of inventory control, classification methods and criteria as well as various factors that are related to classification.

3.1 Inventory control

Classification as a tool to prioritize items for management attention has been common for inventory management for a long time (Flores & Whybark, 1986). This section describes the theory about inventory control that is relevant for this master thesis. The theory about inventory control will include the definitions of tied up capital, economic order quantity, safety stock, safety lead time and service level, which are used in connection with classification of components.

3.1.1 Uncertainties

Two common arguments for holding inventory are economies of scale and uncertainties (Nahmias, 2009, p. 202). Supply chain uncertainty is a broad term that refers to uncertainties that may occur at any point in a global supply chain network (Simangunsong, et al., 2012). In contrast to risks where the outcome is negative, an uncertainty can have both negative and positive outcomes, and therefore also include risks. Supply chain uncertainty is an issue that increases as the company's global presence increases, as well as the potential for delivery delays and quality problems (Simangunsong, et al., 2012).

The uncertainties in a supply chain can be grouped into three different groups; suppliers, internal processes and customers. As mention in Section 1.3, uncertainties relating to supply are the most relevant and will be managed with a classification model of supplied components. Uncertainties that affect the supply can occur due to the company's suppliers and internal processes within the company. Supplier related uncertainties can be variation in lead time, delivery error and quality error.

When the lead time is defined as the amount of time that elapses from an order is placed until it arrives (Nahmias, 2009, p. 202), the company needs to hold safety stock to ensure a smooth flow of production or continued sale, even if the demand can be predicted accurately. The safety stock also protect against quality or quantity errors of delivered products.

Examples of supply uncertainties that relates to internal processes are demand planning, production planning and inventory error.

3.1.2   Tied up capital

Reducing the capital that is tied in inventory is a focus for many companies. Tied up capital affects the ability to finance operations. The company´s return on equity is also affected by the capital that is tied in inventory (Mattsson, 2003). Generally, capital which is tied in inventory represents a significant proportion of the total capital, for an average manufacturing company. Manufacturing companies often tie as much capital in inventory as in plant and equipment assets (Mattsson, 2003).

3.1.3   Safety stock vs. Safety time

A stock represents material or other resources waiting for transformation (Hopp & Spearman, 2011, p. 203). Each item has a certain stock level, which changes as the items are used and replenished with new. To protect the company against variation in demand and other supply uncertainties that may affect the stock level, a safety stock can be used. The safety stock is defined as the average stock on hand before an order arrives (Axsäter, 2006, p. 94). The size of a component's safety stock usually depends on demand, backorder cost, or the service level that the company wants to achieve.

Another way to measure the safety stock is in time, called safety time. The definition of safety time is that an order shall be delivered at least one safety period before it is needed (Axsäter, 2006, p. 209).

3.1.4   Service level

Service level is a common way to determine reorder points and order quantities for a product or a system, and to evaluate the performance of the inventory system. It can be measured at several places within the supply chain. There are three definitions of service level (Axsäter, 2006, p. 94):

- S_1 = $SERV_1$ = Probability of no stockout per order cycle.
- S_2 = $SERV_2$ = Fill rate, fraction of demand that can be satisfied immediately from stock on hand.
- S_3 = $SERV_3$ = Ready rate, fraction of time with positive stock on hand.

An important drawback when using S_1 to determine the service level is that the calculation does not take the order quantity into account. When using the S_1 definition for safety stock calculation, the shortage quantity per period will increase linearly when the order size decreases. To avoid this taking place, the service levels must increase in rate when the order size is reduced. When using

the S_2 definition for safety stock calculation, the safety stock adapts automatically when the order size is decreasing without the service level needing to be adjusted. The safety stock will increase when the order size decreases. This increase depends on the demand variation and will increase as the variation increases (Mattsson, 2005, p. 13). Thus, for large order quantity that covers demand during a long time, a low value S_1 will not affect the service that much. On the other hand, small order quantities can result in a lower service than the expected service level implies. This implies that S_1 is not recommended to use in practice when calculating service level and safety stock (Axsäter, 2006, p. 95). To get a better picture of the real service level the fill rate, or the ready rate should be used, which takes the order quantity into account.

It is not necessary to define service by a probability (Axsäter, 2006, p. 95). Another way to measure service level can be the average waiting time for customers should not exceed a certain number of days. It is not always suitable to have the same service level for all items because of costs and physical aspects. On the other hand, it is impractical to have individual service levels for all items if the company provides thousands of them. Therefore is it common to group items and assign specific service levels to them.

3.1.5   Continuous or periodic review
An inventory control system concerns how the inventory level and inventory position is monitored. It can be designed so that the inventory position is monitored continuously; meaning that as soon as the inventory position is too low, an order is trigged. An alternative to continuous review is periodic review, which means that the inventory is controlled in predefined intervals. Continuous review will reduce the safety stock levels compared to the periodic review. However, it requires continuously inspections, which means a higher cost for inspection, but this is usually not a problem since companies today often use software for inspection. Periodic review makes it easier to coordinate orders for different items to one supplier (Axsäter, 2006, p. 47).

3.1.6   Ordering policies
The most commonly used ordering policies in connection to inventory control are (R,Q)- and (s,S) policies. The (R,Q) policy assume a reorder point, *R*, and a batch size, *Q*. The order quantity *Q* can also be detonated as *nQ* if more than one batch, *n*, is needed. When the demand is continuous, or only one item is ordered at time, the reorder point will always be exactly hit. Otherwise, when periodic review is

used, it may happen that the inventory position is below *R* when ordering and it will therefore never reach *R+Q* units after an order (Axsäter, 2006, p. 48).

The second ordering policy, (s,S) policy, orders up to the maximum level *S* when the inventory position is below a certain level s. In contrast to an (R,Q) policy the order size will not be multiples of a given batch quantity. The (s,S) and (R,Q) policy will be equal if the demand and review are continuous i.e. if the reorder point is exactly hit (Axsäter, 2006, p. 49).

3.1.7 Economic order quantity

A common way to calculate the quantity that should be ordered from the suppliers is to use Wilson's formula. It is based on two different kinds of costs, which are weighted against each other (Lumsden, 2006). The first cost is the ordering cost, which is a fixed set up cost per order. This cost will be higher the greater number of orders that are placed, and will therefore suggest few, large orders. The second cost is the holding cost, which is the cost for keeping inventory. This cost will be higher when inventory levels are higher, and will thus suggest many small orders.

To find the optimal order quantity, these costs are first added together. Also the actual purchase price is included, see Equation 3.1.

$$Total\ cost\ per\ year = TC = pD + \frac{AD}{Q} + \frac{Qh}{2}$$

(3.1)

$$p = purchase\ price\ per\ unit$$

$$D = annual\ demand\ in\ units$$

$$A = fixed\ cost\ per\ order$$

$$Q = order\ quantity$$

$$h = annual\ holding\ cost\ per\ unit$$

The optimal order quantity, denoted Q*, is then derived by determining the minimum point of the total cost curve. Mathematically, this is done by differentiation of the expression with respect to Q, and setting the derivative to 0, see Equation 3.2.

$$\frac{dTC}{dQ} = \mathbf{0} = -\frac{AD}{Q^2} + \frac{h}{\mathbf{2}}$$

$$Q^* = \sqrt{\frac{\mathbf{2}AD}{h}}$$

<div align="right">(3.2)</div>

If the formula should be able to find the optimal value for order quantity, some assumptions have to be fulfilled. First, the yearly demand has to be known and spread evenly over the time period. The purchasing price per unit has to be fixed, and not change over time or due to volume discounts. Another assumption that has to be fulfilled is that the fixed cost per order, often called ordering cost, is constant.

Wilson's formula is often used, e.g. together with an (R,Q) policy, since it is simple to understand and handle, but it has been criticized for the simplified picture of the reality. The underlying assumptions are often not fulfilled in today's uncertain world and the values of the variables used are often hard to estimate, which could lead to sub optimization.

3.2 Classification methods

As mentioned in the *Introduction*, classification allows a company to have control over all components and divide them into various groups, assigned to different strategies. The methodology implies grouping and classifying articles by various industry specific parameters, which are important for the allocation of resources in the company e.g. capital and capacity utilization.

Generally, there are two types of classification; single criterion and multiple criteria methods. The multiple criteria classification uses more than one criterion for classification, and has led to the development of several methods.

The purpose of this section is not to provide the reader with a comprehensive description of all the different methods, rather than to give an overview over the field and what distinguish the methods from each other. Readers who want to know more about one particular method and how to use it in detail are recommended the indicated sources.

3.2.1 ABC classification

The ABC inventory classification analysis is based on the Pareto principal, also called the "80-20 rule". The rule is named after the Italian economist Vilfredo Pareto (1848-1923) who observed that a large fraction of capital tends to belong to a small fraction of the population (Hopp & Spearman, 2011). The ABC classification model was developed by General Electric during the 1950's and have been the most popular way to classify items in inventory (Guvenir & Erel, 1998).

The ABC classification method divides the inventory items into three classes according to the volume value i.e. the dollar value of the annual demand for an item. This since the potential to lower cost for purchased materials depends largely on the purchased amount. The goal with the ABC classification, as mentioned in the *Introduction*, is to manage uncertainties from suppliers in terms of delivered quality, variation in lead time and the company's own inventory errors.

Class A items are of high importance but few in number, where class C is less important, but large in number. Between these two classes is class B, as illustrated in Figure 3.1. The A, B and C classes are normally defined as followed (Hopp & Spearman, 2011):

- A parts are the first 5 to 10 percent of the parts that are accounting for 75 to 80 percent of the total annual expenditures.
- B parts are the next 10 to 15 percent of parts that are accounting for 10 to 15 percent of the total annual expenditures.
- C parts are the last 80 percent of the parts which only accounts for 10 percent of the total annual expenditures.

The objective of the classification is to allocate the company's resources such as capital, inventory management and capacity utilization. Thus, the components allocated to class A are given priority over the other classes.
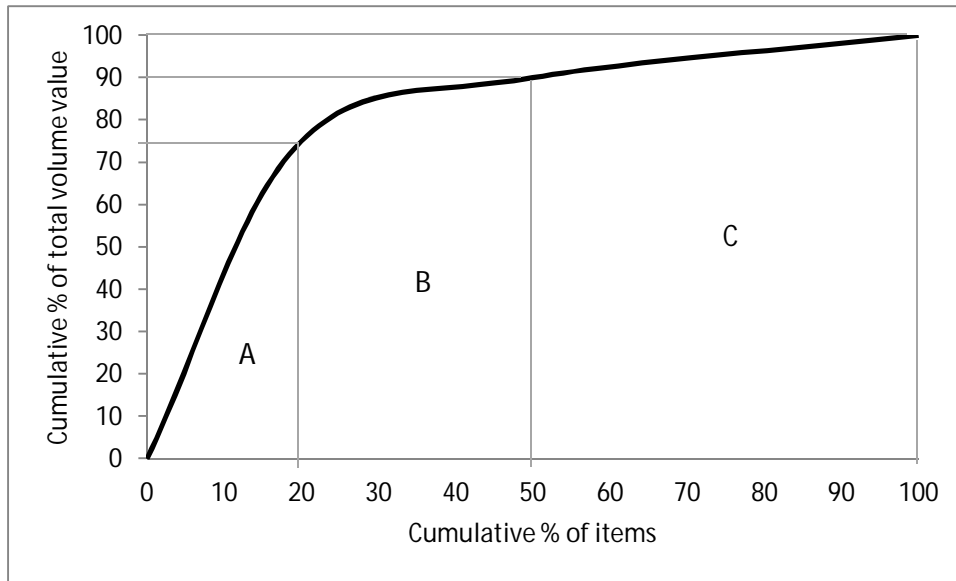
Figure 3.1 Example of an ABC-analysis

ABC classification is easy to use and understand, but the fact that an article has a high volume value does not have to mean that it is crucial and uses the company's resources well. Therefore the ABC classification model has been developed to include more classes and new parameters such as replenishment lead time, inventory holding cost, stockout penalty and durability. It is of high importance that the company chooses parameters that have a confirmed cause/effect relationship with that which shall be streamlined.

3.2.2 Multi-criteria matrix

A development from the classic ABC classification method is the matrix based multiple criteria classification. Flores and Whybark (1986) suggest that more than one measure should be used, to sufficiently describe the managerial needs, and suggest the joint criteria matrix, where two criteria are used. Pursuant to the one-dimensional ABC classification method described above, the items are classified in A, B respective C categories according to the Pareto rule. The matrix places each item in the corresponding cell with respect to both criteria, see Figure 3.2.

Figure 3.2 Multi criteria matrix with two criteria

As can be seen in the matrix, nine different categories can be discriminated. However, to be able to utilize the result, all categories have to have a different policy. Under some circumstances, depending on e.g. which type of industry and which part of the organization that is under consideration, many different categories could be useful, while others might benefit from consolidating some of the classes (Flores, et al., 1992). One possible way of consolidating the categories is to reclassify all off-diagonal items, by either a mechanical procedure, like the example in Figure 3.3, or managerial judgement, which is more commonly used (Flores & Whybark, 1986).

Figure 3.3 Example of consolidation in a multi criteria matrix (Flores & Whybark, 1986)

By extending the traditional ABC classification method by more than one criterion, a matrix with more than two dimensions will occur. The reasoning goes in the same way, and more categories are created. This makes the result far more

24

complex and hard to analyze (Flores, et al., 1992) and therefore, other methods are often recommended if more than two criteria are preferred.

3.2.3   Analytical Hierarchy Process

The Analytical Hierarchy Process, AHP, was first developed by Tomas L. Saaty in the 1970s (Flores, et al., 1992). It is a formalized method for decision-making and is used to rank alternatives in case of multiple criteria. AHP is used when a limited set of alternatives are available, and breaks down an unstructured, complex situation into manageable elements. It can be used in many different situations, for example differentiate inventory items or choose the best supplier bid.

The technique involves pairwise comparisons, which are based on a nine-point scale according to Table 3.1 below (Saaty & Vargas, 2012, p. 6). Some of the benefits with AHP are that it is relative simple to understand and computerize. It can also handle different types of information and manage inconsistency (Nydick & Hill, 1992). Among the drawbacks is often mentioned the dependency of the subjective comparisons and the amount of time it takes from the management, especially if the number of items are large.

Table 3.1 The fundamental scale. Intermediate values are used for additional discrimination.

Value	Explanation
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance

The first step in the process is to identify all criteria that are relevant to the decision (Flores, et al., 1992). These important criteria are then compared pairwise using the above scale, creating a matrix with the weights. An example is shown in Example 3.1 below. Since all criterion compared to itself have to be equal important, the diagonal of the matrix has to consist of ones. Furthermore, if one criterion is preferred to another, the corresponding comparison has to be the reciprocal of the judgment already made. Because of this linked comparisons, in case of n items, a number of $n(n-1)/2$ judgments are required (Nydick & Hill, 1992).

From the pairwise comparison matrix is then the criteria's relative strength derived. This means all criteria receive a weight between zero and one, and that the sum of all weights is one. Mathematically, the weights are the values in the matrix's right eigenvector. The values can also be obtained by transforming the original matrix to an adjusted matrix, and then calculate the mean value for each criteria. How the adjusted matrix is derived could be found in Example 3.1 below. The process in then repeated and all components are pairwise compared to each other, resulting in a weight for each item under each criterion. These are multiplied together to receive the final score.

Example 3.1
Three criteria are considered, called C1, C2 and C3. First, the diagonal in the matrix is filled with ones due to the reasoning above. Then, the judgments of the pairwise comparison are filled in. Criterion C1 is strongly preferred to C2, resulting in the value 5. The corresponding cell receives the reciprocal of that value, i.e. 1/5. In the same way, all the other cells receive values, see Table 3.2.

Table 3.2 Original matrix for Example 3.1

Original Matrix	C1	C2	C3
C1	1	5	7
C2	1/5	1	3
C3	1/7	1/3	1
Column totals	47/35	19/3	11

To find the weights, the values in the columns of the original matrix are summed together. The cells in the adjusted matrix, Table 3.3, are then obtained by dividing the corresponding original value with the column total. The weight is finally calculated as the average value of the row.

Table 3.3 Adjusted matrix for Example 3.1

Adjusted Matrix	C1	C2	C3	Mean value = weight
C1	35/47	15/19	7/11	34/47≈0,72
C2	7/47	3/19	3/11	17/88≈0,19
C3	5/47	1/19	1/11	1/12≈0,08

3.2.4 Fuzzy rule based classification

Fuzzy classifier is an alternative to other traditional recognized classifying techniques (Zhou & Khotanzad, 2007). Zadeh (1965) defines a fuzzy set as a class of objectives with a continuum of grades of membership, ranging from zero to one. Many classification models assume clear criteria of belonging to a category, but in the physical world this is not always applicable. One example of a group in real life could be tall people, where people are more or less belonging. In an inventory context, bulky items or large volumes could for example be relevant classes.

In the usage of fuzzy rules, a membership function assigns a value to each item, describing the grade of membership. The grade of membership for an item x belonging to the set A is denotes as $f_A(x)$. If A is an ordinary set, in contrast to a fuzzy set, the value of $f_A(x)$ is either zero, if the item does not belong to the class, or one, if the item belong to the class. In the case when A is a fuzzy set, $f_A(x)$ can take on all values in the interval [0,1] (Zadeh, 1965).

The membership function is often obtained from an input training data set (Chu, et al., 2008). To generate a satisfying membership function could be hard and complex, but it is a critical step. Medasani et al (1998) have compiled different methods for generating this membership function, with for example methods based on heuristics, histograms, clustering and probability. This membership function could then be used together with ABC classification or genetic algorithms for controlling inventory.

3.2.5 Artificial neural network

Artificial neural network, ANN, is another technique used for classification. It is based on artificial intelligence, i.e. the created intelligence in machines and software. An ANN could be visualized as a network with different nodes. These nodes are called neurons and are structured in hierarchical levels (Partovi & Anandarajan, 2002). In a classification context, it is common to set the input layer as the different criteria used in the model, and the output layer as the classes, see an example in Figure 3.4 below. The layer in between is called the hidden neurons, which are used for the underlying calculations.
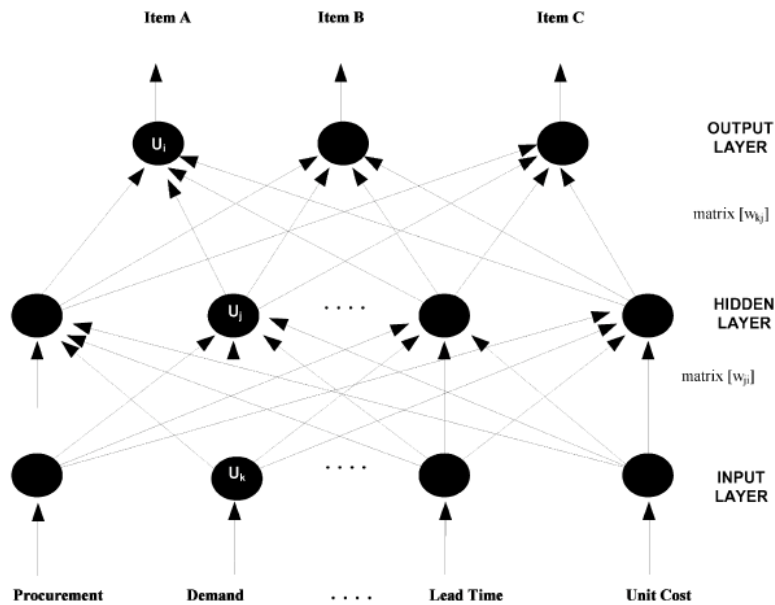
Figure 3.4 Example of an artificial neural network with four criteria (Partovi & Anandarajan, 2002)

The basic idea is that the ANN first is trained by a dataset, with both input and output, to learn the task it is about to perform. There are different methods for learning and among the most common, if the task is classification, is back propagation algorithm (Partovi & Anandarajan, 2002). It scans the data and finds patterns, which are used for constructing non-linear models. An ANN could be seen as a way of imitating a manager's utilization of perceived value and relationship for different items, and could therefore make the process of judgement more efficient, since less manual work is required from the managers.

3.2.6   Weighted liner optimization

One way to address multiple criteria inventory classification problem is to use weighed liner optimization, which is a type of liner programming that is closely related to data envelopment analysis (DEA). The model uses a maximization objective function, see Equation 3.3. A single score, called optimal inventory score, is calculated for each item to add up the performance of an inventory item in terms of different criteria (Ramanathan, 2006). The model to calculate the optimal inventory for the *m*th item with *J* criteria and the total number *N* inventory items is:

$$max \sum_{j=1}^{J} v_{mj} y_{mj}$$

(3.3)

$$\sum_{j=1}^{J} v_{mj} y_{nj} \leq \mathbf{1}, \quad n = \mathbf{1,2,...,} N$$

$$v_{mj} \geq \mathbf{0}, \qquad j = \mathbf{1,2,...,} J$$

The mth inventory item in terms of each of the criteria is denoted as y_{nj}. All the criteria are assumed to be positively related to the significance level of the aim. The larger score an item receives, the greater is the chance for the item to be classified as an A class item. To get the optimal scores for the other items, the model has to be solved repeatedly. The optimal inventory score is then used to classify the items. The processing time can be very long when the number of inventory items is large.

3.2.7 Ng-method
The Ng-method was developed by Wan Lung Ng in the 2000s, to be a more user friendly alternative for multiple criteria classification then the previously described methods, which are considered to be too complex or time consuming to use. The method is no mathematically correct linear optimization method; it is a simplification to minimize the work of classification (Ng, 2007).

The Ng-method is based on a weighted linear method that is transformed to be simpler to use for classification, so that an inventory manager with limited knowledge in optimization can use the model (Ng, 2007). The decision maker has to rank the importance of the criteria, which involves a certain degree of subjectivity. In comparison to AHP, the decision maker only has to rank the criterion and therefore not need to specify a precise degree. All of the parameter values for a component are then converted into a scalar score that is used for the classification.

The following five steps describe the method for classification with J criteria (Ng, 2007):

1. Rank the criteria according to importance, where j=1 is the most important criterion.

2. Calculate all partial averages, $\frac{1}{j}\sum_{k=1}^{j} x_{ik}$, $j=1,2,...,J$, where x_{ik} is the value for the kth criterion of the ith component.
3. Compare and locate the maximum among these partial averages. The corresponding value is the score S_i of the ith item.
4. Sort the scores S_i in the descending order.
5. Group the inventory items by principle of ABC analysis.

The larger score an item receives, the greater is the chance that the item will be classified as an A class item. An example of how to use the Ng-model is described in Equation 3.4 below.

$$Score = max\left[\frac{item\ volume\ value}{\mathbf{max(}item\ volume\ value\mathbf{)}}\,'\frac{\mathbf{1}}{\mathbf{2}}\left(\frac{item\ volume\ value}{\mathbf{max(}item\ volume\ value\mathbf{)}}\right.\right.$$
$$\left.\left.+\,\frac{supplier\ lead\ time}{\mathbf{max(}supplier\ lead\ time\mathbf{)}}\right)'\frac{\mathbf{1}}{\mathbf{3}}...\right]$$

(3.4)

The main advantage of this method is that it is easy to use when having multiple criteria. One of the drawbacks is that the user's rankings of the criteria could have great impact on the result.

3.2.8 Cluster analysis

In mathematics, cluster analysis is a common way to classify data into subgroups called cluster. The method is used to form descriptive statistics where each cluster represents objects with different properties. Similar objects are collected and disparate to objects that belong to other clusters, as showed in Figure 3.5. Cluster analyses are statistical methods of descriptive data that divide data into elements to clarify an underlying structure, or reveal hidden connections in an often multidimensional level.
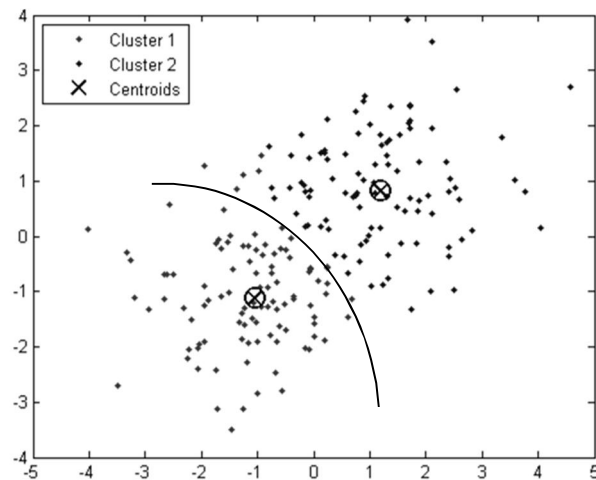
Figure 3.5 An illustration of a K-means cluster analysis (MathWorks, 2014)

Visualization of data can be used for classification in order to identify different clusters, and is suitable for multiple criteria. Each class is assigned to one or several clusters and can be managed in different ways. Cohen and Ernst (1988) recommend a method for clustering control of inventory in industries with large number of diverse items, called operations related groups (ORG) (Ernst & Cohen, 1990).

How the clusters are divided can either be predetermined, or determined afterwards, which is the most common. Four common variants of clustering are described as follows:

– Hierarchical clustering (connectivity based clustering) creates an indexed tree calling dendrogram showing the proximity structure of the data. Dendrogram can be used to identify patterns in the data. By cutting the dendrogram at a certain level, grouping of data can be obtained.
– K-means clustering (centroid-based clustering) aims to create K groups of N data vectors, so that the difference between groups is maximized and differences within groups are minimized. The choice of K-value is done manually.
– Distribution-based clustering is defined as clusters that belong to the same distribution.
– Density-based clustering is defined as areas of higher density then the rest of the data.

31

Generally, cluster analysis requires specific expertise in the field, when the number of clusters is often selected manually and should therefore be balanced for what is considered relevant for the specific purpose. It is paramount to decide what constitutes a good clustering, which is a subjective consideration. Also, the decision on which variables cluster subdivision shall be based on requires knowledge of the subject.

3.2.9 Summary of methods for classification

The classification methods that are presented in the previous sections are summarized in Table 3.4 below.

Table 3.4 Summary of ABC classification and multiple criteria classification methods

| Methodology	Description
Classic ABC classification	The ABC classification method divides the inventory items into three classes according to the annual dollar usage i.e. the dollar value of the annual demand for an item.
Multi-criteria matrix	The multi-criteria matrix is similar to the classic ABC classification and divides the inventory items info three classes in multiple criteria respectively.
Analytical Hierarchy Process	AHP is based on pairwise comparison by the manager, and is a method that calculates a value for each item under each criterion, which then are summed together.
Fuzzy rule based classification	A fuzzy rule based method assumes an inventory item belongs to a class more or less, according to a membership function.
Artificial neural network	Artificial neural network is a model that tries to imitate a manager's decisions. It is first trained by a dataset to be able to perform its task.
Weighted liner optimization	The model uses a maximization objective function. A single score, called optimal inventory score, is calculated for each item to add up the performance of an inventory item in terms of different criteria.
Ng-method	The Ng-method converts all of the criteria measures for an inventory into a scalar score, which is used for classification. The decision maker has to rank the importance of all the criteria.
Cluster analysis	Cluster analyzes are statistical methods of descriptive divide data into subgroups that can clarify an underlying structure or reveal hidden connections in an often multidimensional level. These subgroups are called clusters and can be used for classification.

3.3 Classification criteria

As mentioned in previous sections, there are several other parameters that can be used for classification beside total volume value for an item, which is used for classic ABC classification. These criteria can both be used individually or together with other criteria, called multiple-criteria inventory classification. It is common to use total volume value together with an industry specific criteria (Bose, 2006).

Examples of single criterion classification are presented in Table 3.5 below (Bose, 2006).

Table 3.5 Examples of single criterion classification

Method	Description	Main use
HML classification	Classifies the items depending the unit value of an item, or sometimes the method is defined as the number of each item that is consumed in one year, where H=high, M=medium and L=Low.	To control purchases.
SDE classification	Classifies the items depending on how difficult it is to source a particular item, where S=scarce, D=difficult and E=easy to obtain. A scarce item is not easily available in the market and requires source development, when a difficult item might be an item that is intricate to manufacture (only one or two manufactures). An easy item is readily available.	Purchasing strategies and lead time analysis.
GOLF classification	Classifies the items in the same way as SDE classification but with other categories. G=government controlled, O=open market, L=locally available and F=foreign supplier or imported.	Procurement strategies.
XYZ classification	Classifies the value of the inventory storage. The XYZ analysis is usually made in conjunction with ABC or HML analysis. X=high, Y=moderate, Z=low.	Identifies those items which account for the large amount of money tied in stock.
VED classification	Classifies items on the basis of the relative importance. V=vital (extremely critical), E=essential, D=desirable (not critical)	To control spare parts, determine stock levels.

FSN classification	Classifies the movement of material in stores or of consumption pattern of components, where F=fast moving, S=slow moving, N=Non moving. The demand for fast moving items are generally high and are therefore sensitive against shortage.	To control obsolescence.
SOS classification	Classifies items on the basis of the nature of supplies, where S=seasonal, OS=off-seasonal. Seasonal items can both be available for a limited period or available throughout the year.	Procurement and holding strategies.

The choice of criteria depends upon type of industry/business and whether various parts such as manufacturing, engineering, purchasing and maintenance are involved (Flores, et al., 1992). Two frequently used criteria when using more than one criterion is contribution margin and frequency. The contribution margin represents the portion sales revenue that is not consumed by variable cost (Skärvad & Olsson, 2008, p. 239). It is therefore good in favor to measure how much a product contributes to the company´s profit. However, it is more difficult to use in regards to supply of components since they are used for several products. It may then be better to use frequency as a criterion for how often a component is used.

Other criteria that have been identified in the literature review are: inventory cost, number of request, stockout penalty, scarcity, durability, order size requirement, stock-ability, demand distribution, stock out costs, lead time, part criticality, commonality, obsolescence, substitutability and reparability (Flores & Whybark, 1986) (Ng, 2007).

The above parameters are suggestions that can be used for classification with several components. To select the correct criteria, it is important to understand the industry that the company belongs to (Flores & Whybark, 1986, p. 40), and what factors that are critical for the company.

4 Empirical data

This chapter presents the findings from the gathered data and interviews that the analysis will be based on. The chapter begins with an introduction to the internal processes at The Company and ends with findings from the benchmark part of the thesis. The information about The Company's processes has been continuously collected through interviews with the Director Supply Chain Management and the Supply Chain Developer at The Company during the master thesis process.

4.1 Supply planning and suppliers

The purchasing function at The Company is divided into two parts; sourcing and buying. Sourcing is the more strategic part, which is responsible for long-term relationship with their suppliers and framework agreements. It is in these agreements price and minimum order quantity, MOQ, is decided. The sourcing team is also responsible for securing the supply and manages the supply base strategically. Depending on the product dimension and value, the company is using local, regional or global suppliers. The Company has three centralized sourcing teams, located in Sweden, Poland and China (N, 2014).

The more operative role of the purchasing function is located more close to the production sites. The purchasers at the production sites work with call offs and are responsible for ensuring that components are available when needed in the production. The call offs are done from the framework agreements and are conducted on day-to-day basis. By organizing the purchasing in this way, both the benefits from large-scale agreements and local responsibility are achieved. Especially in the electronic industry, quantity discounts can have a great impact on the final component cost.

When a call off should be made, i.e. an order should be placed, the order quantity is calculated according to the applied ordering policy, see Section 4.2.3. This is then compared with the MOQ, which are agreed for each component. If the MOQ is higher than the suggested quantity, a larger amount than optimal has to be ordered. This is often the case for products that are produced in smaller amount, like products in the end of the life cycles or test batches.

For some components, the corresponding customer is responsible for the supply. This is often the case if the components are unique and provide a competitive edge for the finished product. Some of these components are owned by the customer, also known as consignment stock, and are thus not a source to tie up

capital. The customer itself often manages these stock levels, and the restricting factor from The Company´s perspective is space.

4.2 Planning

This section presents how the inventory planning is made in terms of forecasting and stock levels. It also includes the different ordering policies that are used.

4.2.1 Forecasting

The largest part of the production planning (90-95%) is based on forecasts provided by customers (N, 2014). These forecasts are fully followed, unless the customer wants The Company to plan with extra flexibility. The forecast horizon normally varies between three and twelve months.

4.2.2 Safety stock vs. safety time

To manage uncertainties, both safety stock and safety time can be used. The choice of method depends on where the product that is to be produced is located in the product lifecycle, Figure 4.1. For products in the introduction and growth stage with high uncertainty in demand, safety time is used. This also applies to products that are in the decline stage where the uncertainty increases. Safety stock is only used for products in the maturity stage, where the demand is easier to predict.

Introductory Stage	Growth Stage	Maturity Stage	Decline Stage

Total Market Sales
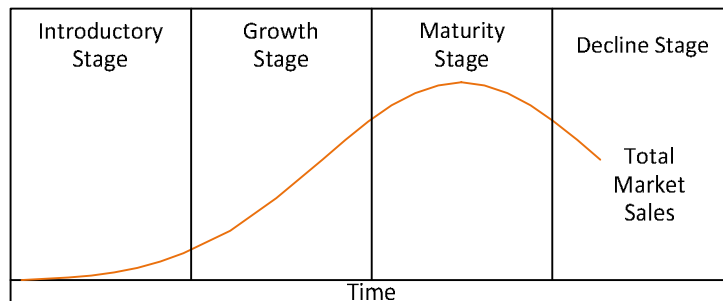
Time

Figure 4.1 Product lifecycle stages

The safety stock calculation is based on the probability of no stock out per order cycle, also called S_1 (Axsäter, 2006, p. 97).

$$Safety\ stock = k \cdot \sigma´$$

$$(4.1)$$

$$\sigma´ = \sigma \cdot \sqrt{Lead\ Time}$$

$$(4.2)$$

36

σ is the standard deviation of the lead time demand and k is the *safety factor* that is related to the predetermined service level. In The Company's case the parameter σ is slightly modified.

4.2.3 Ordering policies

As described in Section 3.1.6, (R,Q) policy and (s, S) policies are the most commonly used ordering policies in inventory control. In purchasing at The Company, three different policies are used (N, 2014).

The first method that is used is called *Lot for lot*, where the system simply creates an order with order quantity equal to the demand during a specified period, e.g. a day. The suggested quantity is adapted to minimum order quantity and multiple order quantity. The policy implies that neither fixed reordering points, nor fixed quantity is specified, and orders occurring in different time periods are not bundled together even if it is the same component. It also implies continuous review since the order proposals are created by the system itself.

A similar policy that is used is called O*rder cover time*, where a specified order cover time is decided. The order quantity is then set to the total demand during this time. An order suggestion is only created if an order must be placed, which is facilitated by continuous review. Compared to the Lot for lot method, this ordering policy generates fewer orders, but higher order quantity per order.

The third method is called *Part period balancing*, which is based on the same reasoning as the economic order quantity formula, see Section 3.1.7. The ordering cost is compared to the stock keeping cost, to find the optimal order quantity. This ordering policy is used for order components.

4.3 The current classification model

Today, The Company uses classification for supplied components to differentiate how to handle them. The model is basically an Excel-file where data from the ERP system is inserted and, by using a macro, the output is received. The output is the class that each component belongs to and safety stock level for each component, as illustrated in Figure 4.2. This is then updated into the ERP system.
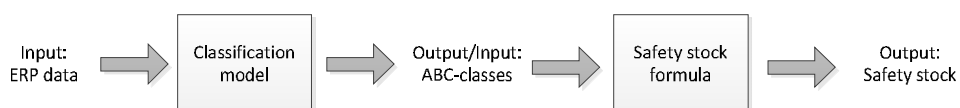
Figure 4.2 Classification procedure

Since the sites are managed individually, each site has the model and uses it with some site-specific numbers. The ambition from the head office is that the model should be run once a month, but this is often not the case. In reality, the sites uses the model more rarely, which could be due to the time consuming manual adjustments, which in many cases have to be done.

All manufactured products are either seen as forecast or order, depending on where in the product life cycle they are. If they are in the mature stage, as described in the previous section, the customer provides The Company with forecasts with a horizon between three to twelve months. If the product is made to order, the customer does not send any forecast and the components are assigned safety time instead of safety stock, see Section 3.1.3.

The current model is based on the classical ABC classification model with volume value as the main criteria. In addition to this is also price per component considered, and if this is high enough, i.e. over a specified level, the item could be assigned a higher class than it should have been if only volume value is taken into account.

The model divides the sites components into ten different classes, where seven is reserved for components that are classified as forecast. These are assigned a level of safety stock based on the specified service level. The service levels are set individually for the different classes and are decided by the sites. They typically range from 50-99%. The service level is defines as probability of not getting stockouts, often called SERV1. As opposed to the most common way, the higher classes at The Company are assigned lower service levels. The reasoning behind is that the higher classes are more manually watched, while articles from the lower classes does not have the same effect on tied up capital but are important to have in stock when needed.

The remaining three classes are reserved for the order components. Since these do not have a forecasted demand, the future volume value is not available and therefore unit cost is used to divide the components into classes. These classes are assigned specified safety time instead of service level.

One problem area that has been addressed in the discussion about the model is the high level perspective on the products. Each customer is seen as unified, which means that the product groups are the same as the customer they are

produced fore. It implies that all the customers' products are seen either as forecast or order.

4.4 Benchmark

The functional benchmarking focuses on processes within the company. Moreover, the benchmark interviews have also discussed the experience of the interviewees in the field, and what they think are most important with classification. The interview guide used during the interviews can be found in Appendix A. As mentioned in Chapter 2, the idea of the benchmark is to interview companies within similar business segments as The Company.

Since the interview covers how the company works with classification, it has been difficult to find companies that are willing to be interviewed. Common explanations from the companies are that they are not working with classifications of components or suppliers, do not have the time, or are not interested. The two last-mentioned reasons are probably because the classification is a part of their strategy, which they are not willing to share.

Two anonymous companies have been interviewed for the classification. These companies operate within two of The Company's business segments.

4.4.1 Company description

This section will give the reader a short presentation of Company X and Company Y, which have been interviewed as a part of the thesis.

Company X

Company X is a global Swedish company founded in the 1960s. The company operates within the medical technology industry and produces both medicines and medical devices. They have a turnover of 11 billion SEK. Company X's production is divided into 13 production facilities in 9 countries. Today, Company X has over 8 000 employees and are represented by sales companies in more than 90 countries.

Company Y

Company Y is one of the world leading companies within industrial air filtration. The company has a global presence with sales subsidiaries in 30 countries and distributors in the same number of countries. Company Y develops and manufactures products at its manufacturing and assembly departments in Europe,

North America and Asia. The company has 1850 employees and a turnover of 3 billion SEK.

4.4.2 Benchmark interview summary
The following section presents a summary of the two benchmark interviews.

*Company **X***

Company X uses two types of classification, technical and commercial. The technical classification deals with the rules contained in the medical industry for sale of medical devises and medicines, while the commercial classification deals with products from a purchasing perspective. The two types of classifications are therefore complementary since they are based on different focus areas.

Technical classification
The technical classification divides the components into three different categories depending on how they affect the end consumer. This classification is technical and fully ignores parameters such as volume or the purchase price.

A component in class A has a direct health or safety risk if anything should go wrong. A B class component has an indirect risk, or a consequential damage risk. C basically implies no risk and consists of products such as packaging materials. As long as a component is used in the same way in the same product, it will stay in its class.

In order to become an A-supplier i.e. a provider of an A class product, it requires more work such as quality agreement and approval of the manufacturer. If a supplier is already approved for an A-item, there are some additional authorizations required in order to start delivering a new A-article. This approval will most likely go a bit easier than for a completely new supplier. This means that it is difficult to add new suppliers and components in the higher classes because it is a long approval processes that takes time. If a component is removed and no longer is purchased, the company is examined to see whether the supplier still has a component in the same class, or if it can be moved down to a lower level. Passive components are weeded out every third year when requalification is done.

The research & development and the quality assurance department at the company are responsible for the technical classification.

Commercial classification

The second type of classification that is used at Company X is a typical ABC classification based on the supplier volume value, and therefore entails a purchasing perspective. The A class suppliers are only about 40-50 strategic suppliers, which accounts for approximately 70% of the volume value.

These are managed globally by appointed category managers. For the A class suppliers, the focus is more on the quality of the component compared to B and C suppliers, which focus more on how the final product is affected of the component.

B class suppliers are regionally managed in three regions, EMEA/APAC/AMERICA, and accounts for approximately 20% of the total volume value. The C class suppliers are handled by factories and accounts for about 10% of the total volume value.

When a new strategy is developed, once a year (or every two years), the classes are reviewed and certain suppliers get reclassified. This means that the rates in each class will change, and it is important that the right suppliers are chosen, particularly for the A class.

The practical work for the classification is done by the purchasing function; how to use a model for the classification. The result from the model will be adjusted manually to reflect organizational conditions e.g. it may not be worth a global effort for an uncritical component. It also depends on how you want to handle a particular supplier e.g. does a critical product need more attention.

About classification in general

The representative from Company X believes that three volume value classes are adequate if the classification should be used in a simple manner. There must be a clear difference between how the classes should be handled. The two types of classification create a dynamic where the technical aspects are weighed against the commercial. Volume value is often used for different kinds of planning within the company and is therefore a good criterion to use for classification. However, using only volume value does not create any value for Company X.

Company Y

Company Y uses a classification for components based on their characteristics e.g. cast components or metal. Otherwise there is no present classification.

The company implemented a software for forecast and stock level optimization for one year ago. The software receives daily information from the ERP-system and calculates safety stock and stock levels based on customer orders and production planning.

The calculations are based on a, for the whole company, given service level (Serv2) and calculates the service level each article needs to have in order to achieve the given service level e.g. can a stable and frequent product have a 99% service level, while a more volatile product has significantly lower service level.

One key objective in Company Y's supplier focus is to reduce the supplier portfolio. This means that the company can concentrate its efforts to fewer suppliers and the company becomes a more significant customer for each supplier. Furthermore, in order to increase the company's market focus, Company Y has started to evaluate a classification based on the market i.e. what customers want.

About classification in general

The representative from Company Y believes that using a model that automatically takes soft values into consideration is difficult and manual adjustments of the results will normally be needed afterwards. It is also important to carefully go through what the purpose of the classification is, in order to prioritize the company's resources in the best possible way.

4.4.3   Conclusion

The following conclusions were drawn after the interviews:

- It is both important and difficult to decide on what the classification should focus on. The focus of the classification should be connected to the purpose e.g. supply regions, markets or inventory levels.
- Volume value is an important criterion in a purchasing perspective to allocate the resources where the impact is greatest, but there is no value by only using that criterion for classification. Therefore, volume value should be complemented with criteria that are industry-specific.
- It is important to have supplier focus in order to improve supplier relations.
- The update frequency can vary and usually depends on how often the components or suppliers are replaced.

5 Data analysis

This chapter presents the analysis and conclusions of the gathered empirical data. The data is analyzed to ensure that it contains enough and relevant information, and relationships within the data is investigated. The purpose is to find parameters that are of interest for the classification of supplied components at The Company.

5.1 Identified parameters

A number of parameters that are relevant for classification have been identified by analyzing data, the literature review, interviewing employees at The Company and by benchmark interviews with companies within similar production. Four different factors that affects the classification and the safety stock levels were found; Supplier, Component, Customer and Operation. From these different areas, a number of causes were identified. A cause and effect diagram can be seen in Appendix B.

5.1.1 Supplier

Three major causes related to the suppliers were identified; delivery dependability, demand and value, see Figure 5.1. By using one or more of these measures as criteria when classifying components, more emphasize is put on the suppliers. For example could one supplier providing several mid-critical components be of greater importance compared to a supplier providing only one high-critical component. This connection might be hidden if only criteria related to the component are considered.

Supplier		
Delivery dependability	Demand	Value
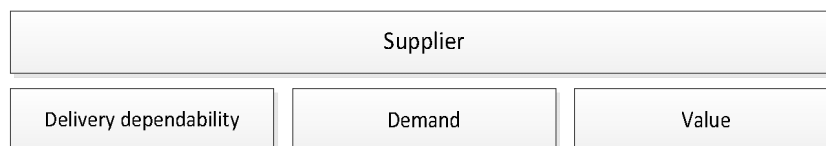
Figure 5.1 Major causes related to suppliers

Delivery dependability

Delivery dependability can be broken down into two different sub causes, which are connected to supplier performance. Variation in lead time, i.e. discrepancies between promised delivery date and actual delivery date affects the optimal safety stock level greatly. If the lead time variation for a specific component is high, a higher safety stock level is needed to not interfere with the production. If only a small component for a product is missing, the whole production can be

affected, with changes in production scheduling and delivery delays to customer as possible consequences. If an order arrives to early compare with confirmed delivery date, the inbound area is affected with congestion and uneven workload as possible consequences. The variation in lead time can be measured both in actual number of days and in standard deviation.

The other sub cause connected to delivery dependability is deviation in quantity or quality from what is ordered. Similar to when a component does not arrive in time, a lack of units or units with to poor quality greatly affects the production. In particular, if a component has a long lead time deviations can be adverse since the mistake is often not discovered until the delivery arrives.

Demand

The second major cause is related to demand from a specific supplier. This can be broken down in a number of different ways, depending on the characteristics on the components. One possibility is to measure number of units, which provides a description of how reliable the production is on one particular supplier. However, neither value, complexity nor criticality is taken into account, which can give focus to small, not such important parts, since these are often more in numbers. One variant is to keep track of numbers of unique components from a particular supplier, which can give a more fair measure. It also reflects the demand and the importance of the supplier, but assigns all components an equal value and is therefore not as likely to give more focus to less critical components.

Another way to look at the demand is to compare the number of orders to a particular supplier, i.e. order frequency. This parameter reflects the collaboration with the supplier and can be affected by purchase decisions. It is therefore not necessary that two components with the same demand pattern show the same number of orders. Another angle is to compare mean order sizes, which are also affected by purchase decisions, i.e. the number of orders for two equal components can vary greatly depending on how the purchaser chooses to divide the orders. The order size can be measured both as number of units and number of components.

Value

The third major cause related to supplier is value. The value could be measured as mean unit cost, volume value for a supplier or mean order volume value. By comparing the mean order cost, suppliers of expensive components would be in focus. Expensive components are often more critical and hard to replace, and the

unit cost could therefore be a fair approximation of the importance. By comparing the mean value, some suppliers can be wrongly judged, since a single component´s value can greatly affect the average, both upwards and downwards.

If volume value per supplier is used as a measure, the focus on high-volume suppliers are increased and purchasing activities can be allocated to suppliers who have high volume values and are therefore of high importance. Both unit cost and number of units affect this measure, and it might therefore be more relevant compared to just looking at one of the dimensions.

The mean order volume value will take into account both order volume and number of orders during a certain time period and can therefore provide a good measure since sporadic orders such as a project order does not have as big of an influence as if only one dimension were to be considered. A possible drawback with this parameter is that the measure can be affected by purchasing decisions or mistakes, and does not necessarily reflect the actual demand. The standard deviation for both types of volume values can be of interest while the demand can be more volatile for some components than others.

5.1.2 Customer

A second factor that can influence the classification is the customer. Since it is the customer who generates the demand, the demand has been identified together with customer value as the major causes related to customers, see Figure 5.2. By using some of these measures as criteria in the classification model, the focus tends to shift to high-value customers. This can give a better delivery performance to the most important customer, but can on the other hand be a disadvantage for new customer, which might be more important for the future.
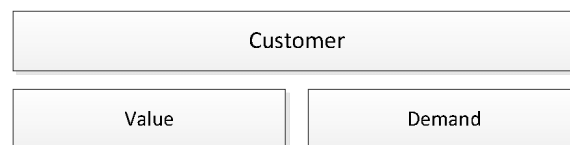
Figure 5.2 Major causes related to customers.

Value

Similarly to when value is evaluated in regards to supplier, the value for customer can be measured both as mean unit cost, volume value per time period and mean order volume value. Mean unit cost is often not such a relevant measure, since an ordered product often contains both cheaper and more expensive components.

45

By aggregating this and also take volume into consideration, volume value is a possible measure. This measure will allocate more resources to already big customers, which might affect the performance to currently small and new customers. To compare mean order value would also reflect the relationship with the customer.

Demand

Customer demand is in the end the crucial demand, which the other demand aspects are derived from. As stated before, the demand can be measured in different ways, e.g. number of units, number of orders, order size or order frequency. Customers will of course request products, and therefore the demand has to be translated into components. The size of the demand can be used as a classification criterion if the purpose is to maximize customer service (Martin & Stanford, 2007, p. 224)

Another cause that can be favorable to evaluate is whether the customer provides The Company with forecasts, or just places orders sporadically. These product categories have different planning horizons and the strategy for handling uncertainties in the supply is different; safety stock is used for forecast components while safety time is used for those that are categorized as order. It is also more difficult to predict the demand for an order, which can be a reason for separating the components when classifying. Another advantage is that the product life cycle is taken into account.

5.1.3 Component

Characteristics of the component itself can also be a factor that influences appropriate safety stock levels. To aggregate the components to either supplier or customer level, can be misleading since the components can be very different and shall therefore not be treated in the same way. Some parameters can only be obtained per component, see Figure 5.3.

Component					
Demand	Value	Phisical size	Lead time	Commodity	Restrictions
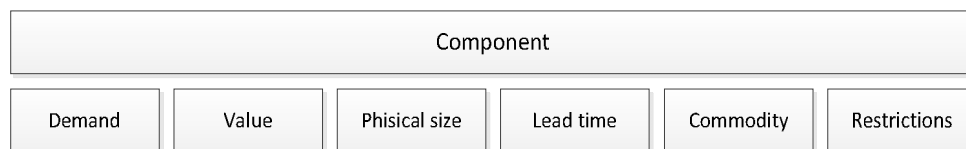
Figure 5.3 Major causes related to components

Demand

Similar to the demand for a specific supplier, the demand for a specific component can be measured in different ways. Number of orders, order size and number of units are all relevant sub causes related to demand for a component. Number of orders reflect the collaboration with the provider, and is affected by purchasing decisions, just like order size. Number of units reflects the actual demand and is not as depending on policies, if the demand is high enough. For components with low demand, the MOQ can affect the ordered number of units. Comparing number of units ignores the value impact of the components.

Value

A second major cause is value, which can be measured both as volume value for a time period, unit cost and mean order volume value. The same reasoning for when comparing value for a supplier is valid when looking at the component level. Volume value for a component would assign more purchasing awareness to components that have large demand and are rather expensive. The underlying reason for assigning components with similar volume value to the same class is that it will facilitate the implementation of managerial cost controls (Martin & Stanford, 2007, p. 224). By only using this measure, the supplier focus is missing and an important supplier can be neglected if not having a particularly important component.

Another possibility to measure value is to look at the value of an order when minimum required quantity is ordered, so called minimum order quantity value. This measure is only a measure for how valuable an order would be and does not take the demand into account. The minimum order quantity value can be a fair measure for classification of low volume components where the order size is affected by the agreed MOQ, but might not give such a rewarding result for components with high demand. For example if the demand is ten times higher than the MOQ, this measure would not provide a good comparison.

Physical size

On the component level, the physical attributes can be equally important to consider. Dimensions and weight have been identified as sub causes that can affect appropriate safety stock levels. For example, a cheap critical component will be assigned a high service level and therefore, theoretically, a high safety stock, while in practice it could be a bulky component that would cause

congestion and overfill warehouses if physical attributes are not taken into account. The same goes for weight, which could be a limitation in the warehouse.

Lead time
One of the most important criteria in the purchasing area is lead time (Flores & Whybark, 1986, p. 40), both the length and the variability of lead time. The length of the lead time dictates the response time for a crisis. The variability affects the amount of safety stock required to provide the service level. A factor that can affect the response time is the components substitutability i.e. if the component has a close substitute, the flexibility increases and response time can be decreased.

The length of the lead times varies greatly depending on location of the supplier and how complex the component is. Items with longer purchase lead time require additional planning and are more sensitive for supply errors in terms of quantity, quality and time, which can be a reason for monitoring these components carefully. This criterion can be measured both in number of days and standard deviation. A similar discussion as for delivery dependability is valid for the variation, see above.

Commodity
Commodity is another major cause identified. A commodity is a group of components based on the components characteristics. It can e.g. consider the cost, complexity and how easy it is to replace the component. It may be more reasonable to have a high safety stock of a unique component, compared to a standard component, which can be bought from a number of different suppliers if shortage will occur.

Restrictions
Apart from what is decided in the organization, additional restrictions from abroad can affect the classification. It can e.g. be safety regulation for chemical substances, or political policies that affects the purchased component. This can affect the handling of components and might therefore be a criterion to include in the classification model.

5.1.4   Operations
The fourth factor that affects classification and appropriate safety stock levels is operations within the organization. Safety stocks in components are kept to protect the organization from uncertainties in supply, with the main objective to

support the production and in the end serve the customers in a satisfying way. Therefore, problems occurring in the production, the warehouse, or in other functions can be reasons to keep higher safety stock of some components, see Figure 5.4.

Operations

Balance error	Production defects

Figure 5.4 Major causes related to operations

Balance errors

Balance error can occur for many different reasons, and result in a deviation between the actual inventory level in the warehouse and the registered inventory level in the system. This can result in shortage if the safety stock is too low. One way to avoid balance errors is by reviewing the physical inventory more often, to adjust differences.

Production defects

Production defects are a second major cause, which highly affects the service level to customers. To address this problem, safety stock might not be a suitable solution in the long run, since it covers up the real problems which should been addressed as it ties up a lot of capital. However, in the short run increased safety stock can be a solution to maintain a high service level towards customers, but in the meantime the production problems are still present.

A second reason can be single unpredicted production defects, which lead to an insignificant outcome and force the facility to manufacture a completely new unit. If any component in that product has a long lead time and no more units are available in stock, this mistake will worsen the delivery performance since a new unit of that component have to be awaited.

5.2   Analysis of obtained data

This subchapter presents the component and supplier data that have been analyzed as well as the results of the analysis. The selection of data is further described in the *Methodology* chapter.

5.2.1   Data for analysis

The ERP-data that has been analyzed is from one of The Company's production sites and it includes the following information:

- – Component demand
- – Component product family
- – Component commodity group
- – Unit cost
- – Minimum order quantity
- – Component purchasing lead time
- – Component supplier
- – Component lead time delivery deviation
- – Component quantity delivery deviation
- – Forecast or order production
- – Forecast horizon

5.2.2   The result of the current classification model

To get an understanding of what the current classification model generates, the number of components that are allocated to each class is presented in Figure 5.5. The data that is used represents one of The Company's production sites. As mentioned in the previous section, class A-G are forecast components, and I-K are order components. Class G contains components that had zero demand in the last classification.
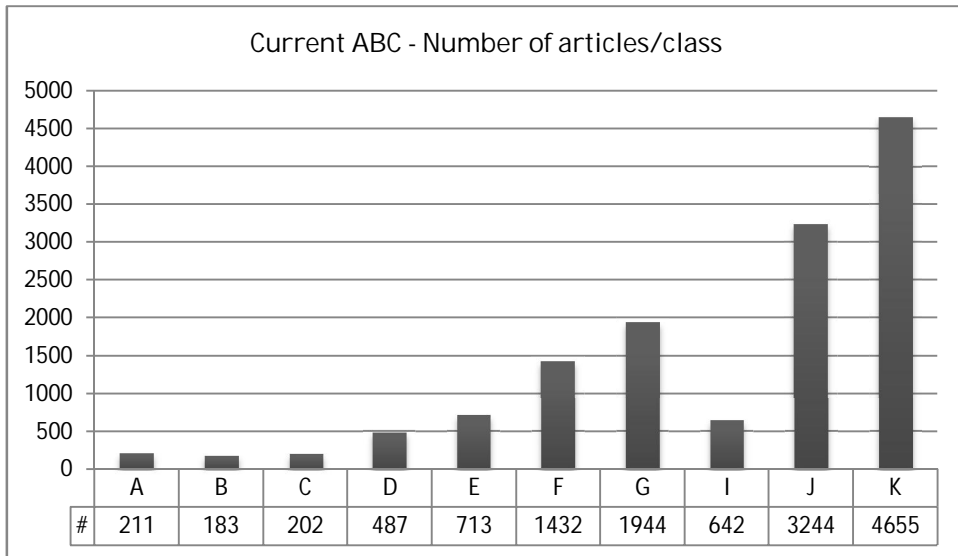
Figure 5.5 Number of articles in each class (current classification model)

The number of components in class A is noteworthy high, which is due to the fact that class A is also used as a default class for new components that have been added and will be reclassified the next time that the model is used. Normally, the number of components in class A is between 10 and 100 (N, 2014).

The volume value for each class is showed in Figure 5.6, for both forecast and order components. As seen in the diagram there is a demand that generates a volume value for components belonging to class G, which should not have any demand at all. The reason for this is that the components have gained a demand since the last time they were classified.
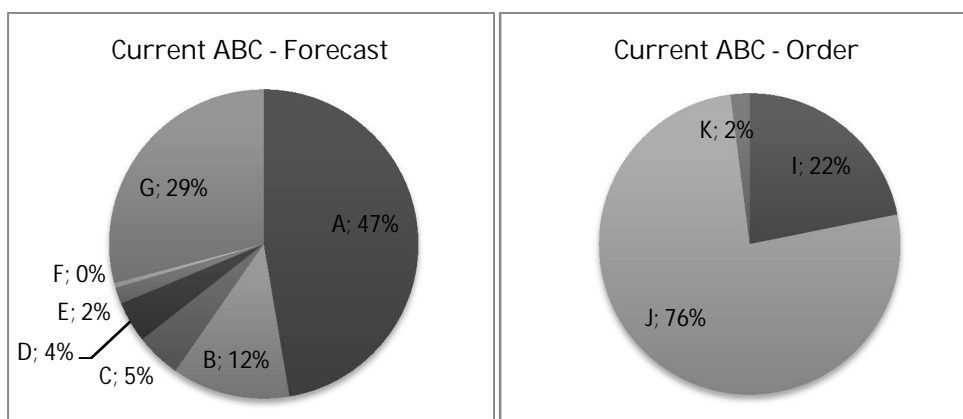
Figure 5.6 Volume value for each class (current classification model)

Generally, it can be stated that the number of components in each class increases drastically, which is a result of few components contributing to a very large portion of the volume value.

When developing the above statistics, it would have been better to use data that had recently been generated from the classification model. For this thesis, it has not been possible to provide such data since it takes months between each time the model is used, as mentioned in Chapter 1.

5.2.3   Basic data analysis

Before a more thorough analysis is performed, it is important to ensure that the received data can be used. The data needs to be homogeneous, which means that the same type of information have to be obtained from all articles to be able to perform an accurate comparisons of the components and suppliers. Table 5.1 below presents the proportions of data that are missing information. Volume value is used as a measure to describe if either the demand or price is missing for the components.

Table 5.1 The quality of the received data

	Items/Value/Suppliers	%
Number of items	13 713	
– Lack of volume value	2 294	17 %
– Forecast items	5 341	39 %
– Order items	8 064	59 %
– Undefined items*	308	2 %
Total volume value	105 937 565	
– Lack of history data	6 222 876	6 %
– Forecast items	79 661 475	75 %
– Order items	26 110 717	25 %
– Undefined items*	165 373	0 %
Number of suppliers**	327	
– Lack of historical data	144	44 %
– With demand	185	57 %

*Unclassified (order/forecast)

**Excluding missing data and dummy

As seen in Table 5.1 the received data is suitable to use. The undefined items that cannot be used in the analysis consists of only 2 % of the total amount of items, and less than 1 % of the volume value.

The volume value can be calculated for a majority (83%) of the items and from those, only 6 % is missing history data. In a supplier point of view, 6 % amounts as much as 44 % of the venders that are missing history data. Moreover, it can be concluded that 75 % of the volume value consist of forecast items, due to the fact that components categorized as order do not have any future demand data.

5.2.4 Supplier performance

The supplier performance can be evaluated in different ways, but this thesis focuses on delivery dependability. As seen in Table 5.2 below, as much as 66 % of the orders are delivered on the wrong day. If a delivery window is used (specified by The Company), the deliveries outside the delivery point will decrease to 31%, which still is a high number.

Because some individual deliveries affect the average deviation, it is better to use the median as a measure of the general deviation, and then use the absolute value as negative and positive deviations otherwise will cancel each other out. As seen in Table 5.2 the absolute median difference for *promised delivery* is 1 day and the maximum is 99 days.

The delivery deviation is based on working days and is therefore not affected by weekends and holydays.

Table 5.2 Supplier performance

	Orders/Days	%
Total number of orders	10 809	
– Number of orders in time	3 586	33 %
– Number of orders within interval	7 405	69 %
Promised delivery time difference (Absolute value)		
– Average	2,33	
– Median	1,00	
– Maximum	99	

Wanted delivery time difference (Absolute value)	
– Average	4,41
– Median	1,00
– Maximum	240

The delivery time difference is defined as the difference between promised delivery date and actual delivery date. In the histogram in Figure 5.7 below, the performance of all 10 809 orders during 2013 are presented. It is possible to see how the deviations are concentrated around zero. However, there are a number of deliveries where the deviations are much larger, thereby affecting production planning since it can be enough that one component of a product family is missing in order to delay the production. Also too early incoming deliveries can be a problem when the warehouse management is overloaded.
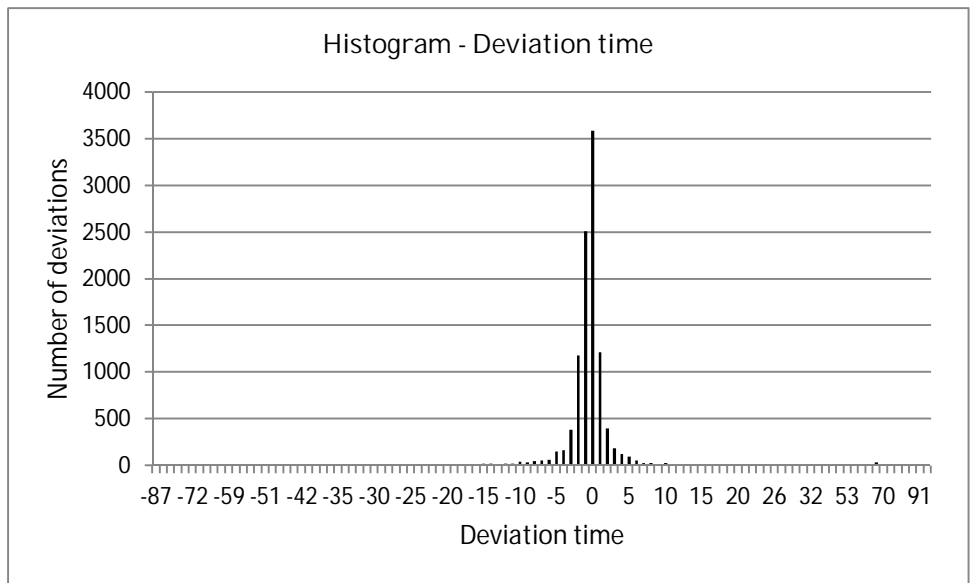
Figure 5.7 Promised delivery time difference in number of days

An alternative way to look at the supplier performance is to investigate the difference between wanted delivery date and actual delivery date, as illustrated in Figure 5.8. This measure can be seen as a measure of the supplier availability i.e. how often a supplier can meet the company's requirements. In the diagram it is possible to observe that the deviations follow the same distribution, but with

larger average and extreme value, as can be read in Table 5.2. As in previous analysis, the analyzed data is from all arrived orders during 2013.
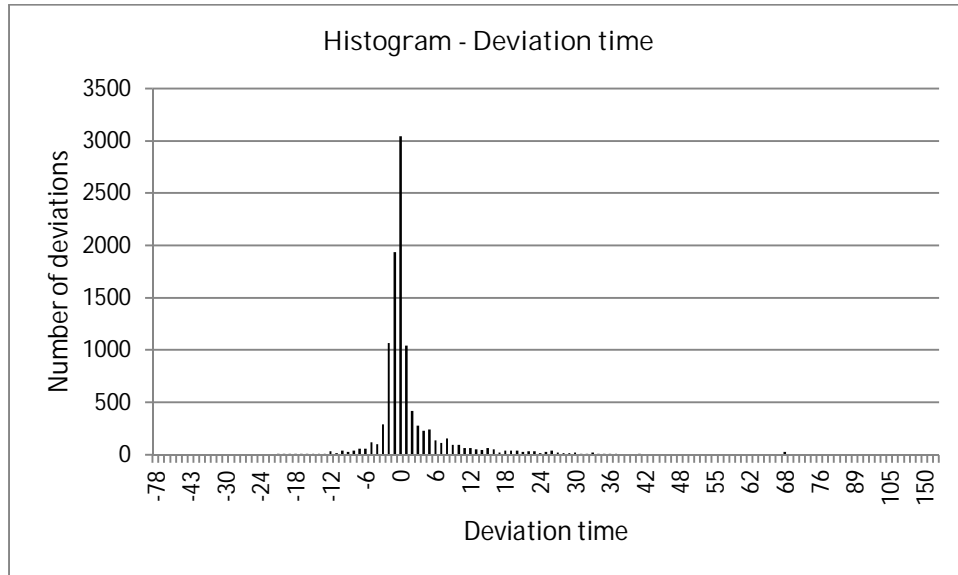
Figure 5.8 Wanted delivery time difference in number of days

5.2.5 Demand

One way to evaluate how much the various components or suppliers affects the purchasing activities within a company, is to study the demand. As seen in Table 5.3, the maximum demand varies a lot compared to average numbers for both the components and suppliers. This makes the demand a good parameter to differentiate components or suppliers from each other.

Table 5.3 Evaluation of demand

	Items/Value
Total number of components with demand	4 334
Number of components per supplier	
– Maximum	1 203
– Minimum	1
– Average	23
– Median	3

Demand per component	
– Maximum	713 615
– Average	3 234
– Median	398

5.2.6 Volume value

The volume value is evaluated with regards to component and supplier. The difference between the largest and smallest volume value for both the supplier and the component is sizable. This makes the volume value a good parameter to differentiate components or suppliers from one another. It is also possible to see that the component with the maximum volume value occupies 7% of the total volume value where the supplier with a maximum value of volume occupies 35% of the total, see Table 5.4. This means that it may be interesting to increase supplier focus. It may be added that the 25 suppliers of totally 185 suppliers with demand represents 90% of the total volume value, as illustrated in Figure 5.9.

In the same way as the supplier analysis, 297 components (6,9 %)of total amount of components with demand represents 90 % of the volume value, as illustrated in Figure 5.10.

Table 5.4 Evaluation of the volume value

	Value	
Total volume value	105 937 565	
Supplier volume value		
– Maximum	36 889 898	35%
– Average	560 516	
– Median	36 696	
Item volume value		
– Maximum	7 359 310	6,94%
– Average	24 443	
– Median	572	
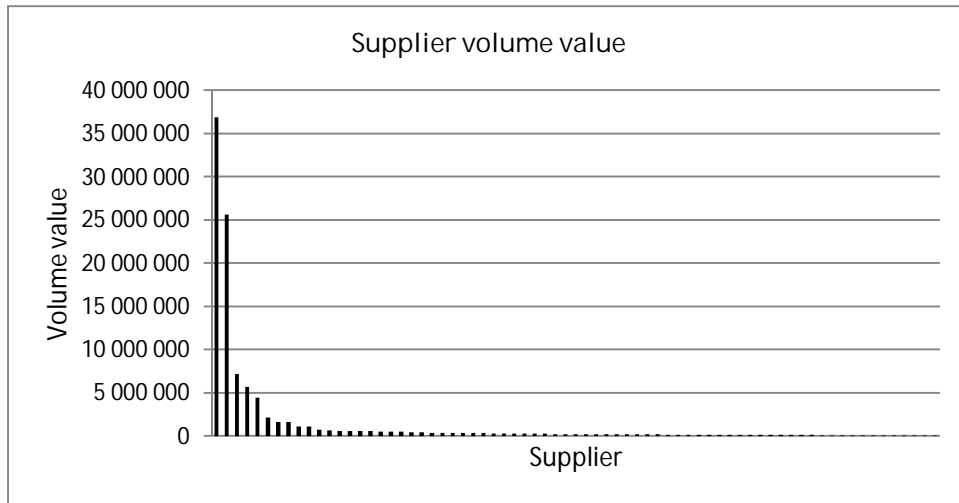
Figure 5.9 How volume value varies between suppliers (in decreasing order). Only data for the major suppliers that together contribute to 98% of the total volume value is shown.
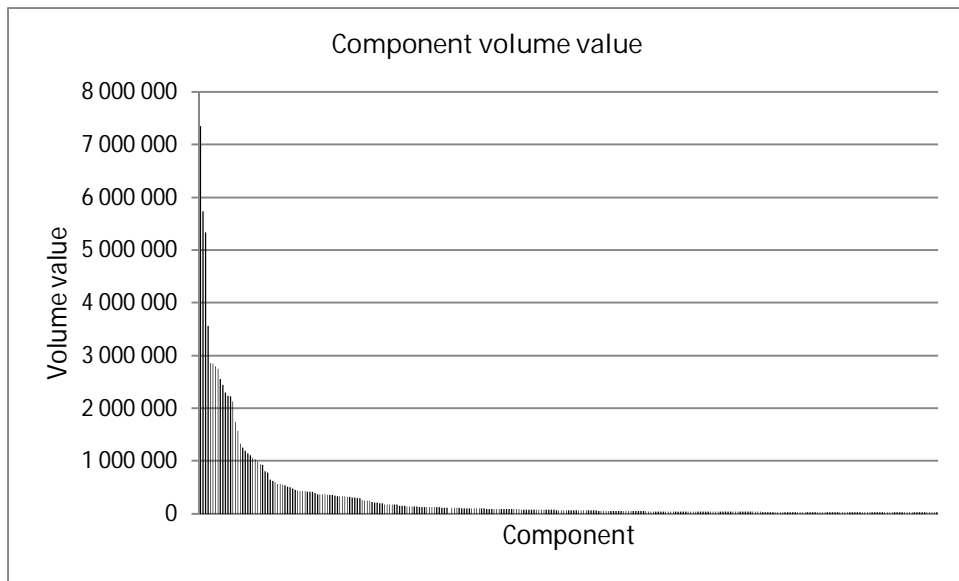
Figure 5.10 How volume value varies between components (in decreasing order). Only data for the major components that together contribute to 90% of the total volume value is shown.

Further analysis of the volume value, it can be observed that the Pareto curve of the forecast and orders are slightly different from each other, see Figure 5.11. The curve for order components has a much softer deflection due to fewer components with extremely high volume values. In neither case is it possible to identify any clear classifications.
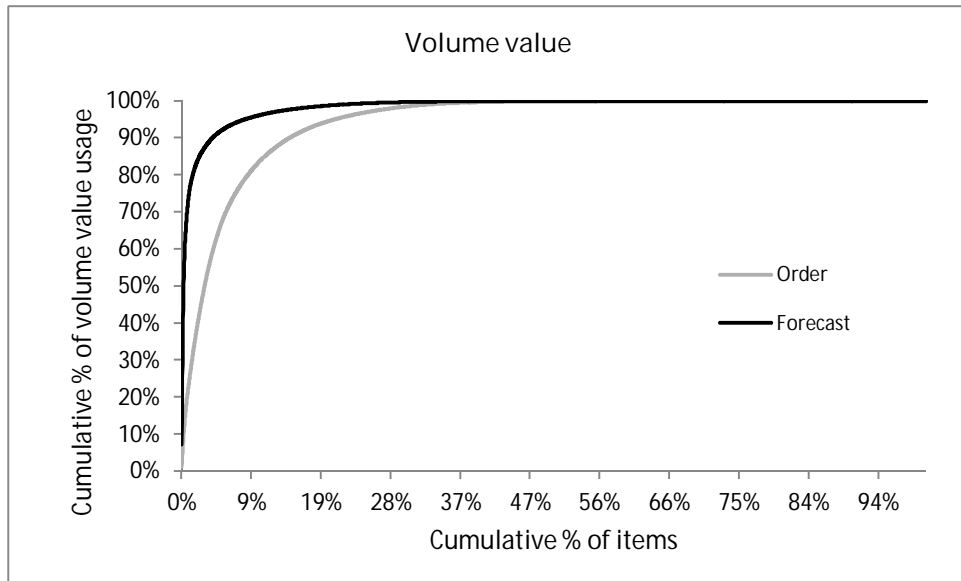
Figure 5.11 Cumulative forecast volume value based on demand data and cumulative order volume value based on historical data.

5.2.7 Commodity groups

The commodity groups are evaluated to be a measure for degree of standardization. As seen in Table 5.5, the gathered data for commodity groups are good. Less than 1% of forecast components and 5 % of order components are missing data. This shows that the commodity data can easily be used both for the analysis of this thesis and in future classification at The Company.

Table 5.5 Evaluation of the commodity data

	Items	%
Total number of analyzed components	13713	
- Forecast with demand	3108	
- Order with demand	1226	
Number of components missing commodity info		
- Forecast with demand	1	0,3%
- Order with demand	62	5%

The commodity data is further analyzed to observe if it is possible to group components after their substitutability i.e. can components of the same commodity group with low average unit cost, be considered less critical than

58

commodity groups with higher average unit cost. For such analysis, a boxplot is made in order to evaluate the distribution within each commodity group. The boxplot (see Appendix C) shows that most of the commodity groups have large unit cost spreads, which makes it difficult to use commodity to measure the degree of standardization.

5.3   Relation analysis of obtained data

A second step in the analysis of the data is to examine how different parameters affect each other. Through various conjunction analyzes between parameters, conclusions can be drawn. Conclusions can be taken by finding natural classifications, or by finding correlations between the parameters. For example if it is possible to find correlations between two parameters, it can lead to a reduced number of parameters in the model. A simple course when analyzing a large amount of data is to illustrate the data in charts in order to find different patterns or clusters.

By plotting the two criteria supplier volume value against the component volume value, it is possible to see clear lines that represent the suppliers and how their components' volume value differs from each other, see Figure 5.12. In most cases, the high supplier volume value depends on a high number of components. In the diagram, a diagonal line, illustrated as a dashed line, can also be observed that limits the component volume value, which can be explained by the fact that a component can never have a higher volume value than the component supplier.
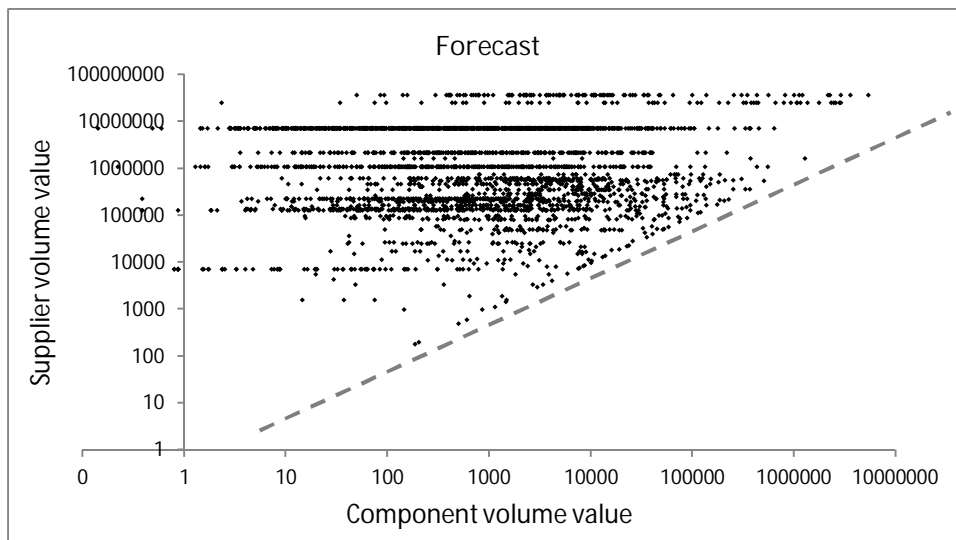
Figure 5.12 Volume value for 5341 forecast components and associated 168 suppliers

59

It can be seen in Figure 5.13 that it is not possible to observe any correlation between the supplier volume value and supplier delivery performance. Thus, providers of high delivery values are not better at delivering on time. The diagram in Figure 5.13 shows the analysis of 133 forecast suppliers who have available data for lead time standard deviations.
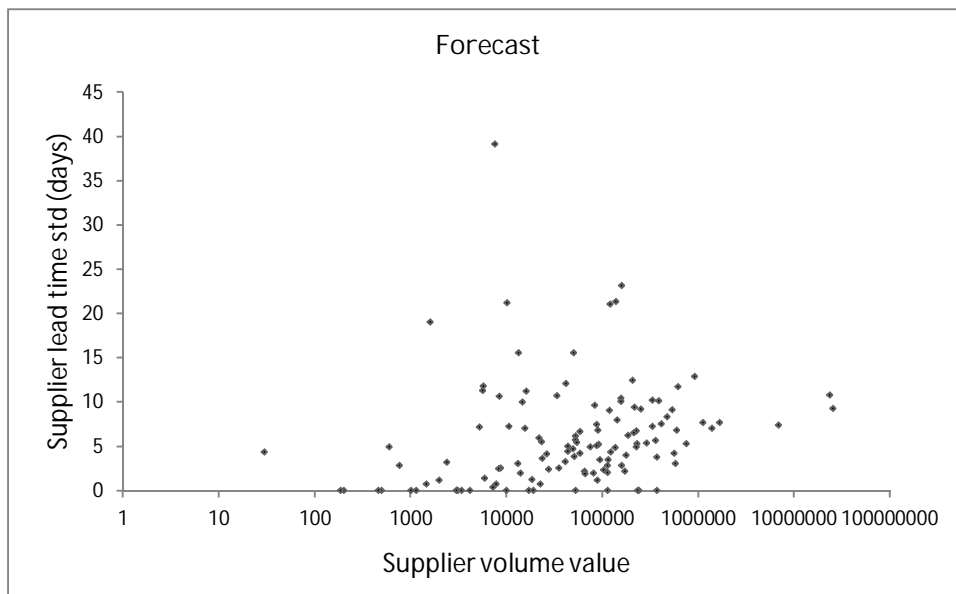
Figure 5.13 Supplier lead time and volume value for forecast items

When comparing the average supplier lead time deviation with the number of orders it is possible to observe that the deviations decrease as the supplier's deliveries increase, see Figure 5.14. This is because an individual delivery impact on the supplier performance decreases, as the number of deliveries gets higher. However, there are exceptions where providers with a high number of orders after all have poor supplier performance.
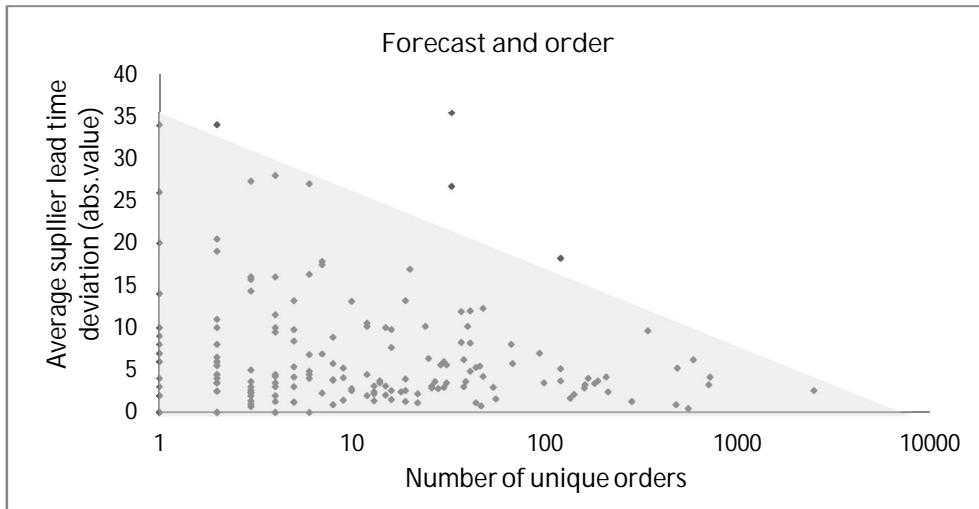
Figure 5.14 Number of unique orders and average supplier lead time deviation (195 suppliers).

6 Model

The outcome of this thesis is to suggest a model for classification of supplied components that challenges the model that is currently used, and give recommendations on how to use it. This chapter will present and discuss the classification methods and the parameters that are identified as suitable to use in the model. Number of classes and number of articles in each class will also be discussed.

6.1 Requirements for the model

When developing a model for classification, it is important that the model meets both the general requirements for how a classification model should work and the specific requirements that must be met in order to apply the classification model in The Company's activities. The most general requirement for a classification model is that it should provide reliable and useful results. It includes assigning the components to appropriate classes, with a reasonable number of components in each class, to achieve the purpose of allocating the company's resources in a fair way.

The classification model that is used by The Company must be applicable for their type of business, which means that the model should work with the amount and the type of components that The Company have in all their business areas. The approach shall be able to handle the combination of used criteria and shall not require any manual correction of how the components are divided into classes.

The model must also be easy to work with, to facilitate usage at the sites. If the model is considered to be too complicated or require much work, it will not be used as often as it is supposed to. This can result in dramatic changes once it is run, instead of fine tuning as desired. As part of facilitating the usage, the model should be able to be updated with Excel.

6.2 Choice of parameters

Choosing parameters to use as criteria in a classification model is a critical step in formulating the model. There are a number of different aspects to consider when selecting which parameters should be used and which would be deselected.

Today, The Company distinguishes the work between forecast and order components and handle them in different ways. This means that the data available differs between the categories. As described in Section 5.1, the different parameters require different kind of data, and therefore different parameters

might be used for forecast and order components. This division is relevant since it allows The Company to treat products in different stages of the product life cycle in a suitable way, see Section 4.2.2, and therefore the separation is reasonable to retain.

6.2.1 Quantitative or qualitative data

One aspect to consider is whether quantitative or qualitative criteria should be used. Many of the described models in the theory chapter use quantitative criteria, since these are often available in the ERP system. Qualitative measures are often translated to a quantitative figure instead, and can thereby also be used in the models describes.

Quantitative data is also more intuitive to understand, and the difference between components can be measured numerically. This gives the model more trustworthiness and it can therefore be more used and utilized by managers at the sites.

6.2.2 Selected parameters

When identifying possible parameters to use, see Section 5.1, some were found to be more suitable than others. After discussions with The Company, these were reviewed and three different parameters where selected. These were selected as a group since they were considered to complement each other and give an idea of the complex reality that all the different parameters represent. The three parameters represents three different perspective; economic impact, supplier performance and degree of standardization.

As a first criterion, *volume value per component* is chosen to represent the economic impact. The benchmarking interviews concluded that volume value (Equation 6.1) is an important criterion in a purchasing perspective to allocate the resources where the impact is greatest. The unit cost is often an indication of how important the component is for the end product, or how hard it is to source and together with the volume for that particular component, it gives a fair measure of the importance of the components for the company.

$$Volume\ value = yearly\ demand \cdot unit\ cost$$

(6.1)

For components categorized as order, or due to other reasons does not have a predicted demand, volume value calculated with forecasted volumes are difficult to use. Neither historical demand is available for components that belong to new

products. An alternative is therefore to use unit cost as a criterion, but then the volume perspective is ignored. Minimum order quantity value will consider both unit cost and volume, and can be a substitute for volume value when the demand is unknown. Since not all order components have a value for the minimum order quantity, the value that is used for the volume is the maximum value of minimum order quantity and multiple order quantity, see Equation 6.2.

$$Minimum\ order\ quantity\ value$$
$$= max(minimum\ order\ quantity, multiple\ order\ quantity)$$
$$\cdot unit\ cost$$

(6.2)

The second criterion selected is *supplier lead time standard deviation*, which is a measure to evaluate the supplier performance. It is selected since the arrival of ordered components has a great impact on stock levels and sufficient safety stock. In the historical data for supplier performance it can be found that 69 % of the placed orders are delivered within the delivery window. This implies that there exists a noteworthy uncertainty whether an order will arrive in time or not, which should affect the purchasing decision. Since new components are added regularly for which no historical data is available, the lead time deviation is measured per supplier, to facilitate adding new components from already existing suppliers. This is justified with the reasoning that it is the supplier who is responsible for the delivery, and the components that are involved are not crucial.

The third parameter that is chosen as a criterion for the new model reflects the degree of standardization of the component, i.e. how hard it is to substitute the component with similar components or with deliveries from other suppliers. If a component is unique for The Company, the lead time is often long since it has to be produced, and it is not possible to turn to another supplier if a delivery is missing. On the other hand, standard components can have many different suppliers and is relatively easy to get hold of if shortage occurs. To catch this characteristic of the component, unit cost is used as the third parameter since it is considered to be a fair approximation of the degree of standardization. Standard components are often cheap since a wide range of suppliers are available, while engineered components with only one or a few sources are more expensive.

A better parameter for capturing the degree of standardization would be a ranking system where the components are graded after how easy they are to source. The different categories can for example be standard electronics, complex

manufactured components, engineered components and single sourced components. This is not possible for this thesis but can be further investigated.

6.2.3   Deselected parameters

By selecting these parameters, other parameters are deselected. All parameters related to customers are excluded since an increased supplier focus is desired. Since The Company has an explicit goal to lowering the capital tied in component stock, this is probably not a decisive choice, as there are other factors that have a higher impact on tied capital. Parameters related to operations within the company are also excluded since neither balance errors nor production defects are considered major problems.

Parameters related to physical size and weight are also deselected since it is not relevant for tied up capital and therefore not the purpose of the classification. The dimensions of the components can still be used when calculating safety stock levels to avoid congestion, but not in the classification model itself.

Demand in number of units is deselected in favor of volume value, where the unit cost is also included. Other aspects of demand, such as number of orders, order frequency, order distribution and order size were not chosen since these are affected by the call offs from the purchasing organization, and do not reflect the actual demand. The order frequency and order size can also be unevenly spread over the time period, which makes them unreliable to use as a criterion.

All parameters regarding demand aggregated to supplier are excluded since the component volume is of greater importance. The same reasoning is behind deselecting value aggregated to supplier level. If increased supplier focus is desired, volume value per supplier is a good alternative to volume value per component. In this case, it is not chosen since focus on the suppliers is achieved by using supplier lead time standard deviation as a criterion.

Parameters related to delivery dependability and lead time for each component are not selected since the equivalent parameter for supplier was preferred. This is due to the fact that many components are ordered from the same supplier and the supplier lead time deviation also has a smoothing effect.

No relevant restrictions are found for the industry that The Company works within, which can be used for classification of supplier components.

6.3 Use of parameters

A second step after choosing parameters that are of interest for the classification, is to choose how these will be measured. Quantitative data can be measured in many different ways for example: values, percent, average, variance, standard deviations, or correlation factors. To determine how to use the data in the classification model it is of importance to understand the underlying purpose.

6.3.1 Historical or predicted data

One aspect to consider when identifying suitable parameters to use as criteria in a classification model is if historical information or predicted data should be used. If more than one parameter is considered, they can be combined. One of the advantages with using historical data is that it is objective and based on what actually happened, and are therefore not depending on predictions of the future. Another reason to use historical information is that the data is often already available, and does not need to be created for the classification. One of the disadvantages with using historical data is the lack of information a new component would face. Since new components have not been used by the organization before is historical data not available, which would demand a model that can handle missing data.

To use data that tries to reflect the future can be difficult, since it is subject to uncertainties. One advantage is that it is focused on the future and what is to come, instead of the past. This would lead to better handling of the products' life cycles and demand volatility, which would prepare the organization for the work ahead. Other reasons can be that the lack of historical data for new components is not a problem, or that the predicted data has already been gathered for other reasons, for example forecasts to plan the production schedule.

Historical data is reasonable to use if the manufactured products have long product life cycles and stable demand, and few new product introductions are made. If the products are characterized by the opposite, short product life cycle and unstable demand, can predicted data be of better use since the future and the past probably would differ. In some cases future data can be hard to obtain, and therefore historical data has to be used.

For the new model, both historical and predicted data are desirable to use. If forecast data is available, regarding for example future demand, it should be used in favor of historical information. For other criteria such as supplier lead time deviation, historical information is more reasonable to use since it reflects the

supplier performance in the past. If the supplier has not undergone major changes, it is reasonable to assume that the behavior will continue.

6.3.2   Volume/MOQ value

Since the volume value is a combination of value and demand, it is not appropriate to calculate this parameter in any other way than the value. This reasoning is also used for minimum order quantity value. To capture the future demand, forecasted volume is used where it is available. This means that predicted data is used in favor of historical data, to keep focus on the future. A high minimum order quantity value/volume value for a component means that it is assigned to a higher class in the classification.

6.3.3   Supplier lead time deviation

The supplier lead time deviation is calculated using the historical standard deviation from previous deliveries. There is no difference if a component with 50 or 10 days lead time is five days late, as they both will affect the planning with five days. Consequently, it is not appropriate to calculate the deviation as percentage of the lead time, and therefore standard deviation is used. The standard deviation is a statistical measure of how much different the value deviate from the mean value.

When using the standard deviation, it is important to be aware of the drawbacks. The more values that are analyzed, the better the evaluation of the standard deviation is. When using a small amount of data, the standard deviation can give a false picture, which also applies if the data contains extreme values.

If a high deviation should indicate a high or low class can be discussed, and depends on the circumstances. In this case, a low class implies a higher safety stock level, and therefore a low deviation is recommended a high classification.

6.3.4   Unit cost

Since the reason for having unit cost as a criterion is to capture the components degree of standardization, it is reasonable to measure it in actual value. If there is a difference in historical cost, the current price should be used, unless the cost is known to be changed in the near future. For a higher cost, a higher class is appropriate.

6.4 Evaluation of classification methods

In the theory chapter, seven different classification methods were described, whereof six consider more than one criterion. These were chosen since they reflect different areas in the field of classification, and provide a good overview over which methods are used. They are all suitable and high performing under the right circumstances, but should be carefully used when the conditions not are appropriate. However, some of the methods are inadequate to use at The Company´s sites.

The model currently used at The Company can be seen as a single criterion method with volume value as the criterion. The volume value is perceived as an important criterion to consider at The Company and it should therefore preferably be one of the criteria used in the new model. Consequently, all single criterion methods are deselected in favor of methods that consider several criteria.

The first multiple-criteria method that were found unsuitable for The Company's circumstances were the Analytical Hierarchy Process, AHP. Since the sites have a huge amount of unique components, the manual work required for this method will be overwhelming. Even if the initial comparison between the current components were made, each new article would implicate a massive effort to classify. Therefore, the AHP is excluded as a possible method to use when classifying purchased components at The Company.

Artificial neural network, ANN, is a method that tries to imitate a manager's choice. This method requires a training data set, with both input and output, for the model to learn how to make decisions. In other words, the model cannot perform better than the training data set, which has to contain both data regarding all the components and which classes they belong to. In The Company's case, preparing such a data set would apart from acquiring a lot of work, solve the issue of how to classify articles in a suitable way, which is the main problem the new model should give answer to. ANN is therefore not suitable for The Company, and is excluded from further investigations.

Regarding the fuzzy rule based classification method, the identification of a membership function is the most critical step. Also, this method needs a training data set, to be able to find a satisfying membership function, and there is no single best method to obtain it (Medasani, et al., 1998). After discussions with The Company, the method is excluded because of its complexity and the amount of work that would be required to set up the model. Other methods are assumed to

perform equivalent with less effort and result in a more understandable and acceptable model.

The weighted linear optimization method is a valid mathematical method for optimization. However, to get the optimal score for each item, the model has to be solved repeatedly, which results in a very long processing time when the number of inventory items is large. In comparison with the Ng-method, the weighted linear optimization method is more complex for the user to understand and might therefore not be used as frequently as desired. The weighted linear optimization method is therefore excluded in favor of the Ng-method.

Since three different criteria are used, the multi criteria matrix is also ruled out. The reason is that the method becomes unmanageable when the matrix is three-dimensional, and it becomes hard to analyze and use the outcome (Flores, et al., 1992, p. 73). A matrix in three dimensions would generate 27 classes, which have to be combined in one way or another, but no natural way or guidelines for doing so exist.

When the methods above are excluded, two methods are remaining; Cluster analysis and the Ng-model. These will be subject to further analysis and a comparison between them can be found in the Section 6.7.

6.5   Number of classes

The output of a classification model is a number of classes where the components are allocated. The literature study has not resulted in any conclusive guidelines on the number of classes to use. Teunter et al. (2010, p. 344) argues that the number of classes is usually limited to six when components are classified. Generally, it can be stated that the number of classes depends on the purpose of the classification and what is practical to manage. There must be a reason to use for example four instead of three classes.

For single criterion classification, as ABC classification, is it common to study the Pareto curve to see if it is possible to find clear boundaries, as illustrated in Figure 6.1.
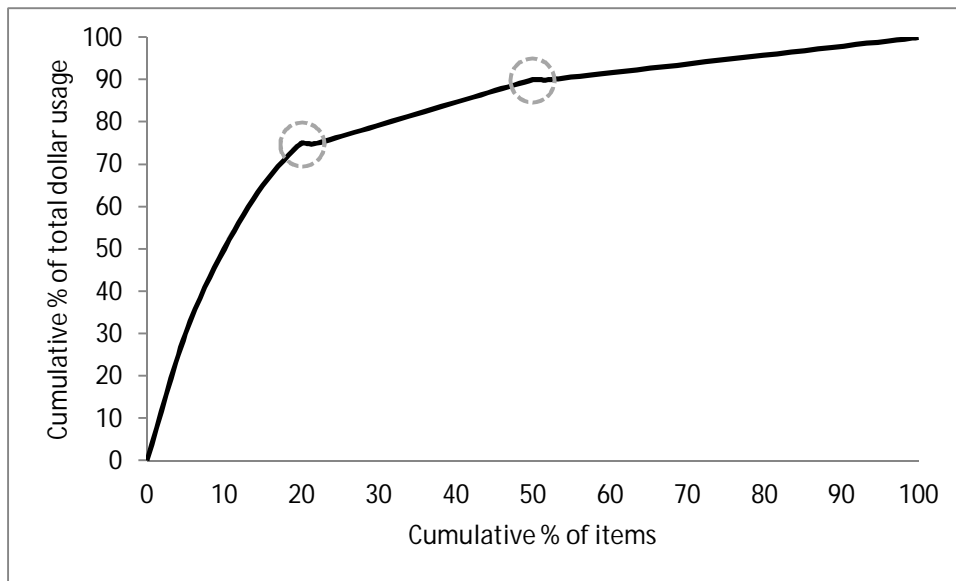
Figure 6.1 Example of clear boundaries in a Pareto curve

Clear boundaries are possible to observe when using multi criteria methods that accounts one score for each component. However, there is a risk that it is not possible to observe any boundaries and this risk will increase when a large number of components are classified. This makes it difficult to put reasonable limits between classes. For example, is it reasonable to put two components with only a fraction of difference in two different classes?

If the classification method results in too many classes is there a possibility to reclassification of the classes by merging them, and thereby decrease the number. This method is presented as an alternative for multi criteria matrix (see Section 3.2.2), where nine classes are reduced to three. Using three instead of nine classes implies only three inventory policies (Flores, et al., 1992, p. 73).

When using cluster analysis, there is a possibility to optimize the number of clusters (MathWorks, 2014), but it entails a risk that the number of clusters are changed every time the classification analysis is updated. This makes it difficult to work with inventory policies.

In the case of The Company, who uses classification to group components by different safety stock levels and accordingly allocate purchasing resources, the number of classes is determined with regard to how many different service levels they want to use. Until the method for how to determine the service level has

been further evaluated, the new model continues to work with The Company´s current division, seven classes for forecast and three for orders, which follows the above recommendations. This is to facilitate the implementation of the new model and since no basis for another division exists. Since the purpose of the classification model is to minimize tied up capital and the classes are differentiated in determined service level, it is reasonable that the model generates many classes.

6.6 Number of articles in each class

A second step after determining the number of classes to use is to determine the proportion of components that should belong to each class. The main question, when it comes to determining the number of components in each class is: How many components is the company able to effectively control?

As described in Section 3.2.1, *ABC classification*, the proportion of components in each class can follow the 80-20 rule. This rule of thumb may also be used in other context than the volume value (Ng, 2007, p. 344), but when using more than the volume value as a criterion it may certainly be that the components allocated to class A occupy a smaller portion of the total value than 20%. The 80-20 rule can only be used when using a classification model that calculates a score for each item and is therefore not useful for methods such as multi criteria matrix and cluster analysis. The 80-20 rule is useful as it allows the management to focus their attention on the most critical areas, or the areas with highest pay-off (Flores, et al., 1992, p. 72) when it is used in conjunction with volume value.

For methods as cluster analysis the number of components in each class are generated by the method, as described in Section 3.2.8.

Another less controlled approach on how to select the number of components in each class is presented by Warren and Standford:

> *Each class is formed by inclusion of some sequential percentage of the SKUs, based on ranking if all SKUs on some criterion of interest; the percentage of SKUs allocated in to a particular class is usually a reflection of past experience* (Warren & Standford, 2007).

Instead of using rules to determine the number of components in each class, there is an option to use the experience within the company. However, this

requires that the experience exists and that it is easy to transfer it to those who work with the model.

6.7 Comparison of classification models

In this section, a comparison between the two remaining classification methods, i.e. Cluster analysis and the Ng-method, is performed. They are both compared to the ABC classification. To compare different classification methods is complex due to, among other things, difficulties in setting boundaries for the classes, i.e. deciding how many classes should be used and how many components there should be in each class.

The comparison between the classification methods is done separately for forecast and order components respectively. This is primarily due to the purpose of the classification, i.e. to assign appropriate safety stock and safety time for the components respectively, and the two categories must therefore not interfere with each other. The other reason is due to practical circumstances, since the comparison will be easier to perform in two steps. This will not influence the result, since the classes are separated between forecast and order components.

6.7.1 Comparison of forecast components

The comparison of forecast components is based on the classical ABC classification, with volume value as the only criterion. The boundaries are set according the suggestion from Flores et al. (1992, p. 72), where the components in the A class accounts for 70 % of volume value, while the B ranked components accounts for the following 20 %. This resulted in 43 components in the A class, 190 components in the B class and 2716 components in the C class. To make the comparison unbiased, only components with data for all selected criteria are considered.

Three classes are used since it is the standardized way to use an ABC classification. Another reason is to facilitate the comparison between the methods, which makes the analysis for the final choice less complex. The reason for not comparing with the current classification at The Company, is to avoid comparing with misclassified components, see Section 5.2.2.

When performing a cluster analysis, the method itself is creating the classes. For the example data, a k-mean cluster analysis with three cluster results in 11 components in the A class, 44 components in the B class and the remaining 2894 components in the C class.

To be able to use the Ng-method, the criteria have to be ranked. After discussion with The Company the hierarchy is selected as volume value, supplier lead time deviation and finally unit cost, due to the target of minimize capital employed and secondly increase the supplier focus. To create the classes, the same distribution as for the ABC classification were generated, i.e. 43, 190 and 2716 components respectively.

The result of the comparison can be seen in Table 6.1, where it is stated if and were the components change class, compared to the original ABC classification. Table 6.2 shows how big portion of the components stayed in the same class, and how many that moved one respectively two steps in any direction. As can be seen, the cluster analysis method is more similar to the ABC classification compared to the Ng-method. It can be observed that the cluster analysis method created classes with fewer components in the higher classes, with the result that redundant components are moved one step further down.

Table 6.1 Result from the comparison of classification methods for forecast components

	Ng-method	Cluster (k-mean)
A → A	14	11
A → B	5	32
A → C	24	-
B → B	9	12
B → A	9	-
B → C	175	178
C → C	2520	2716
C → A	20	-
C → B	176	-
Total	2949	2949

Table 6.2 Portion of forecast components that stayed respectively changed class

	Ng-method		Cluster (k-mean)	
	Components	%	Components	%
Stays in class	2540	86,1	2739	92,9
Moves one step	365	12,4	210	7,1
Moves two steps	44	1,5	321	0
	2949		2949	

6.7.2 Comparison of order components

When classifying the order components, the methods are again compared to the classic ABC analysis. This time with unit cost as the criterion, since it is the parameter used for classifying order components at The Company today. The boundaries were set to above 1000 monetary units to qualify for the A class and more than 10 monetary units to qualify for the B class. These boundaries were chosen to achieve a similar distribution as when the forecast components were classified, and are similar to the boundaries used in the current classification model. This resulted in 73 components in the A class, 1628 components in the B class and 3165 components in the C class. A total of 4866 components were classified, which includes all order components with data available for all selected criteria, i.e. minimum order quantity value, supplier lead time deviation and unit cost.

A similar approach as for classifying forecast components is used, i.e. three different classes are created and the ABC classification and the Ng-method generate the same number of components in their classes. Regarding the cluster analysis method, the different classes contain 248, 1021 and 3597 components respectively (see Appendix D). For the Ng-method, the same ranking between the criteria as in the first comparison is used, with minimum order quantity value replacing volume value.

The result from the comparison of order components is presented in a similar way as for the forecast components, in Table 6.3 and Table 6.4. It can be observed that neither of the methods are similar to the classical ABC classification, due to the two additional criteria. The number of components the cluster analysis places in the A class is also notably low.

Table 6.3 Result from the comparison of classification methods for order components

	Ng-method	Cluster (k-mean)
A → A	7	-
A → B	15	8
A → C	51	65
B → B	490	171
B → A	32	1
B → C	1106	1456
C → C	2008	2945
C → A	34	4
C → B	1123	216
	4866	4866

Table 6.4 Portion of order components that stayed respectively changed class

	Ng-method		Cluster (k-mean)	
	Components	%	Components	%
Stays in class	2505	51,5	3116	64,0
Moves one step	2276	46,8	1681	34,6
Moves two steps	85	1,7	69	1,4
	4866		4866	

6.8   Choice of classification model

In light of the comparison above, one of the methods has to be chosen as the suggested method for The Company to use in their new classification model. One of the main requirements for the recommended method is that it should be able to handle the parameters selected as criteria. Both of the compared methods, the Ng-method and the cluster analysis method fulfill this claim; otherwise the comparison would not have been possible.

As can be concluded from Section 6.7.1 and Section 6.7.2, the cluster analysis method performs significantly different between the forecast components and the order components. For the latter, none of the components assigned to the A

class in the ABC classification remains in the cluster analysis. Furthermore, the way the classes are created in the cluster analysis is unpredictable and does not facilitate the processes at the organization. This is due to the fact that components considered as the most divergent are grouped together, which can make the class complex to control since the components would ideally be managed quite differently from each other (Ernst & Cohen, 1990).

The Ng-method on the other hand is more predictable and cannot change dramatically when a few new components are added. Another benefit is that the method is quite flexible and more criteria could be added if deemed necessary, without massive changes in the method as a consequence. Further possibilities are to assign a criterion a lower impact by adjusting the formula used for calculating the final score, see Section 3.2.7.

If many different criteria is used for the Ng-method, the ranking of the criteria is not an easy assignment (Ng, 2007), but it can have a major impact for the classification result. Since only three criteria are selected, it is seen as a manageable task to perform. If significantly more criteria are considered in the future, the Ng-method might not be the most suitable due to the high impact an unreasonable ranking can have.

According to the above reasoning, the Ng-method is considered to be the most suitable for The Company to use, when classifying purchased components. It is selected since it is relatively easy to use and accept, as well as it provides the user with reliable and predictable classification results.

7 Results

This chapter presents the results and findings of the thesis. The recommended model is presented together with the validation of the model and the assumptions that are made during the development of the model.

7.1 Model approach

The following five steps describes the model for classification with three criteria and *i* components (Ng, 2007):

1. Rank the criteria according to importance, where j=1 is the most important criterion.
2. Calculate all partial averages, $\frac{1}{j}\sum_{k=1}^{j} x_{ik}$, *j=1,2,3*, where x_{ik} is the value for the *k*th criterion of the *i*th component.
3. Compare and locate the maximum among these partial averages. The corresponding value is the score S_i of the *i*th component.
4. Sort the scores S_i in the descending order.
5. Group the inventory items by principle of ABC analysis.

The larger score an item receives, the chance that the item will be classified as an A class item becomes greater. The equation for forecast components is described in Equation 7.1, and the equation for order components is described in Equation 7.2. These equations represents step two and three in the model description above. Note that the only difference is that the volume value is replaced with MOQ value.

$$
\begin{aligned}
Score &= max\left[\frac{item\ volume\ value}{\mathbf{max(}item\ volume\ value\mathbf{)}}, \frac{\mathbf{1}}{\mathbf{2}}\left(\frac{item\ volume\ value}{\mathbf{max(}item\ volume\ value\mathbf{)}} \right.\right. \\
&\left. + \left(1 - \frac{supplier\ lead\ time\ std}{\mathbf{max(}supplier\ lead\ time\ std\mathbf{)}}\right) \right), \frac{\mathbf{1}}{\mathbf{3}}\left(\frac{item\ volume\ value}{\mathbf{max(}item\ volume\ value\mathbf{)}} \right. \\
&\left.\left. + \left(1 - \frac{supplier\ lead\ time\ std}{\mathbf{max(}supplier\ lead\ time\ std\mathbf{)}}\right) + \frac{unit\ cost}{\mathbf{max(}unit\ cost\mathbf{)}} \right) \right]
\end{aligned}
$$

(7.1)

$$Score = max\left[\frac{item\ MOQ\ value}{\mathbf{max(}item\ MOQ\ value\mathbf{)}}, \frac{\mathbf{1}}{\mathbf{2}}\left(\frac{item\ MOQ\ value}{\mathbf{max(}item\ MOQ\ value\mathbf{)}}\right.\right.$$

$$\left.+ \left(1 - \frac{supplier\ lead\ time\ std}{\mathbf{max(}supplier\ lead\ time\ std\mathbf{)}}\right)\right),$$

$$\frac{\mathbf{1}}{\mathbf{3}}\left(\frac{item\ MOQ\ value}{\mathbf{max(}item\ MOQ\ value\mathbf{)}}\right.$$

$$\left.\left.+ \left(1 - \frac{supplier\ lead\ time\ std}{\mathbf{max(}supplier\ lead\ time\ std\mathbf{)}}\right) + \frac{unit\ cost}{\mathbf{max(}unit\ cost\mathbf{)}}\right)\right]$$

<div align="right">(7.2)</div>

As a low supplier lead time standard deviation is recommended a high classification, see Section 6.2.2, that part of the equation has been recalculated to $1 - \frac{supplier\ lead\ time\ std}{\mathbf{max(}supplier\ lead\ time\ std\mathbf{)}}$.

7.1.1 Components that are missing data

If the volume value is zero, i.e. either predicted demand or unit cost is zero, or missing, the component is immediately assigned the lowest class among the forecasted components, i.e. class G. It is therefore vital that the unit cost is accurate, especially for components with high estimated demand. The order components where the unit cost is zero are treated in the same way, and are placed in the lowest class for order components.

If a new component is introduced to the production and the supplier has not been used before, no historical data for the supplier lead time deviation is available. To be able to use the model in any event, either a value has to be assigned, or the method has to be adjusted for only two criteria. By adjusting the Ng-method, the unit cost ranked as the third criterion will immediately have a higher impact on the score since it is now seen as the second most important criterion. This could lead to an unreasonable classification since the components will be assigned their score under different conditions. It is therefore recommended to assign all components with missing data for the parameter supplier lead time deviation, a value of zero. This will be favorable for those components, that can be assigned a higher class, which is reasonable for a newly introduced supplier and component.

If an order component is missing data for minimum order quantity, or multiple order quantity, the value will be replaced by 1, see Equation 7.3, since it is the lowest possible purchased quantity and does not contribute to any

overestimation of the component. However, there will be a risk of underestimation of the component.

$$Minimum\ order\ quantity\ value$$
$$= max(minimum\ order\ quantity, multiple\ order\ quantity, 1) \cdot unit\ cost$$

<div align="right">(7.3)</div>

7.1.2 Output from the suggested model

When the above described model is used on all 13 713 components, all components are linked to their associated score. The result can be seen in Table 7.1 below. The boundaries for the forecast classes are set close to the distribution suggested in Section 6.6, i.e. the 80-20 rule. Since a combined score is used instead of e.g. volume value, the 80-20 rule in this case means that 20 % of the most important components should be allocated to the first class, if three classes are used.

Since there are seven classes reserved for the forecast components, the A-D classes together allocate approximately 20 % of the forecast items, when the items without volume value is excluded. These are bundled together to avoid a huge number of components in the higher classes, which would affect the allocation of resources negatively. The division of the classes mutually is also done according to the 80-20 rule, where e.g. class A and B together allocate 20% of the components in classes A-D. The G class is reserved for all forecast components that do not have a volume value.

For the order components, only three classes are used. The components that do not have a unit cost are placed in the lowest class together with components that achieved a low score. The boundaries are set to distribute the components as 10, 20 and 70 % respectively.

Table 7.1 Result from the suggested model

	Forecast	Order
A	20	829
B	82	1621
C	102	5894
D	396	
E	612	
F	1797	
G	2360	
Total	5369	8344

One drawback with the model is that many components can get the same score, which makes it difficult to control where the class boundaries should be. Since the boundaries are set as a fixed score, some similar components might end up in different classes. This is often not reasonable, but it is a consequence for many of the classification models described in this thesis. To remedy this phenomenon, the management's expertise can be applied to fine-tune the generated classes, as discussed in Section 6.6.

7.2 Validation of the model

For this thesis, it is not possible to test how the suggested model works in reality. That is because the model has to be used for a long time to be able to get a sense of how the results differ from the current model that The Company uses. A new model may also require significant management changes for those who operate with purchasing and supply at The Company. Finally, the effects of an improperly functional model can be immense. To avoid such problems, those who work with purchasing and supply must be extra observant during the first time using a new classification model, which is resource consuming. Nor is it possible to just select some components for the validation of the model, as the model's purpose is to allocate the company's resources in a good way based on the total amount of components that are purchased.

The above reasoning has led to the method and the associated parameters to be validated through discussions with stakeholders, i.e. employees that are involved

in the results and thus may contribute to a performance assessment, as described in Chapter 2.

The selected parameters have been evaluated by continuous discussions with The Company, to understand what is important to their business. Suggested parameters have been presented and subsequently discussed to validate their validity. Also the hierarchy of the three criteria is discussed with employees, to secure a reasonable ranking by the authors. Through the validation, it can be concluded that the criterion for degree of standardization is relevant for most components. However, the approximation described in Section 6.2.2 is not always valid as there are components with high prices that are easy to obtain. This varies depending on the production site that the component belongs to. One example is metal sheets with high unit cost that normally have several sources, which means that it cannot be considered as a critical component.

The model has been validated through review of the methods presented in Table 3.4. These methods have later been reduced through discussions according to Chapter 6. As a second step in the validation of the model, the output of the model is compared with the output of the classical ABC classification, as described in Section 6.7.

7.3   Assumptions

There are several assumptions that need to be accounted when performing data analysis and when suggesting a classification model. The main assumption taken for the data analysis is that the received data representing one production site also represents the other production sites that produce other types of products. This, despite the fact that there are different types of manufacturing that takes place in the production sites, as well as the manufacturing volumes varies between the production sites. Furthermore, it is assumed that the data collection period of one year is a long enough time interval.

7.3.1   Demand

When calculating the volume value it is of importance that the forecast demand data describes what the future demand looks like. An assumption that must be taken in connection with both the analysis of data and the use of the classification model is that this demand data gives a fair enough picture of the future demand.

7.3.2   Minimum order quantity

As MOQ is used to calculate a substitute value to volume value for order products, it is of importance that these values are correct, in order to affect the classification properly. It is also assumed that it is not common to order smaller quantities than the predetermined minimum order quantity.

7.3.3   Supplier performance

The historical lead time difference is based on estimates of how suppliers have performed historically. In these calculations it is assumed that the expected delivery date and actual delivery date is correct in the ERP system, i.e. the delivery dates have not been renegotiated.

A basic assumption is that suppliers will approximately continue to perform equivalent to what they have previously performed. Furthermore, it is assumed that historically lead time deviation is a fair measure even for suppliers who have only delivered a few times.

8 Conclusions

This chapter presents the conclusions that can be drawn from this thesis. The fulfillment of purpose of the thesis is discussed as well as recommendations to The Company for further research within this field. The chapter will end with the academic contribution of the thesis.

8.1 Conclusions about classification

This master thesis includes the analysis of classification methods and their associated input and output data as a model, as showed in Figure 8.1.
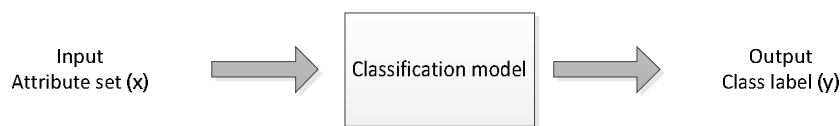

Figure 8.1 Aim of the master thesis

The input data consists of a number of parameters that are selected based on the purpose of the classification, and how complex the classification model should be. This data can both be quantitative and qualitative. The qualitative data generally requires more work by the user, in order to be useful in a model.

Depending on how many parameters to take into account, both single and multiple criteria methods can be used for classification. In multiple criteria classification, several different methods have been developed with primarily two main objectives; give better results and be easier for the user to use. Both methods where the criteria have to be ranked and methods where all criteria are equally important exist. Generally, it can be concluded that greater number of criteria requires more advanced models, which restricts the selection of models.

The output classes are the third part to determine. This includes number of classes and the amount of article in each class. The number of classes depends mainly on what is possible in a management perspective. To justify the use of many classes, there has to be a clear difference in how the classes are handled. If components in two classes are treated in the same way, the classes can just as well be combined.

Deciding the number of articles in each class is a more difficult task. The classes are often unequal in number of components, where the higher classes contain

fewer articles. The 80-20 rule or by experience is two possible ways to handle the problem.

To utilize the results of the classification model in a good way, it is important for The Company to assign the right service level for each class and calculate the safety stock levels in a satisfying way. It is also important that the model actually is used frequently, to avoid dramatic changes when the result from the model is imported to the ERP system.

Furthermore, various collaboration strategies between suppliers and the company can affect the classification results. Internally produced components may also affect the classification, as these generally do not have regulated delivery requirements.

8.2 Conclusions about safety stock calculations

The different components used by The Company have different demand patterns that depend on whether they are manufactured to forecast or order as well as the length of the production cycle.

As mentioned in the theoretical chapter, Section 3.1.4, an important drawback when using S_1 (the probability of no stockout per order cycle) to determine the service level, is that the calculation does not take the order quantity into account. For large order quantity that covers demand during a long time, a low S_1 will not affect the service that much. On the other hand, small order quantities can result in an increased shortage quantity per time period i.e. a lower service than the expected service level implies. This implies that S_1 is not recommended to use in practice when calculating service level and safety stock. In order for The Company to get a more accurate picture of the service level that their procurement function has against production, they should use the fill rate (S_2), or the ready rate (S_3), which takes the order quantity into account. If using the S_2 definition instead for the safety stock calculation, the safety stock adapts automatically when the order size is decreasing without the service level needing to be adjusted. The safety stock will increase when the order size decreases.

8.3 Fulfillment of purpose

The purpose of this thesis is, as described in Chapter 1, to suggest a model for classification of supplied components at The Company, which challenges the current model. The authors claim that this purpose is fulfilled, through the analysis in Chapter 5 and the construction of the model in Chapter 6. The analysis

is based on Chapter 3 and 4, which results in discussions anchored in reality and a solid theoretical foundation.

The other aspect of the purpose is that the classification model should be applicable for all of The Company's business segments and sites. This cannot be guaranteed since the data analysis and the conclusions are based on information from one specific site. However, by not choosing site/business segment specific parameters, the ability to use the classification model at several production sites increases.

Three different research questions were formulated, which have to be answered in order to achieve the fulfillment of the purpose, see Section 1.2.

8.3.1   Research question R1

The initial research question concerns parameters that are suitable and possible for The Company to use as criteria, in order to classify their supplied components.

> *R1: Which parameters are suitable to use to classify supplied components at The Company?*

This question is answered in Section 6.1.2, where it is argued which parameters that should be used as a criterion and why. It is concluded that volume value per component, supplier lead time deviation and unit cost should be used as the three criteria from all of the identified parameters in Section 5.1. To legitimate the selection, it is also argued why the rest of the parameters are not chosen, in Section 6.1.3.

8.3.2   Research question R2

The second research question relates to how these selected parameters should be combined, i.e. which classification method should be used to classify supplied components with regards to the three chosen criteria.

> *R2: How should the parameters be combined for classification?*

The answer to this question could first and foremost be found in Section 6.8, where the Ng-method is chosen as the most suitable to use under The Company's circumstances. The answer is based on the evaluation of classification methods, which can be found in Section 6.3, and the comparison of the most suitable

methods in Section 6.7. A brief overview of all classification methods that have been subject for evaluation can be found in Section 3.2.

8.3.3   Research question R3

The third research question concerns how many classes the model should result in, and how the components should be divided into these classes.

> *R3: How many classes are reasonable to use and how should these classes be divided in order for the model to be useful?*

This question consists of two parts, which are answered separately. The first part of the question regarding how many classes are reasonable to use, the division used in the current classification model is recommended, i.e. seven classes for forecast components and three classes for order components. The second part, regarding the number of components in each class, is answered in Section 7.1.2, where it is stated that the boundaries should be set according to the 80-20 rule. The reason for this recommendation can be found in Section 6.5.

8.4   Difficulties during the thesis

The main problem the authors experienced during this thesis is related to the collected data. A common difficulty that has appeared during this project is the lack of data for some of the components in the ERP system, which has complicated both the execution of the analysis and the conclusions that are possible to draw from the result.

Other related problems are incorrect data for some of the components, which results in a process of data clearing, or outdated information, which has changed since the extraction. Difficulties in getting access to the data and understanding the accessed data correctly have also been noticed during the thesis.

8.5   Recommendations

This thesis has laid a foundation for how a new classification model at The Company can be constructed. However, some suggestions for future research exist, which would make the result of this project even more useful and valuable. The recommendations are divided into a short-term and a long-term perspective.

8.5.1 Short-term recommendations

The short-term recommendations focus on how to improve the use of the current model at the company and the work with classification.

It is of importance to ensure that the current model is regularly used to avoid large differences in the reclassification, since a large part of the produced products have a life cycle of less than one year. While the product in the beginning and end of the life cycle are manufactured to order, and in between made to forecast, it is important that this product is reclassified within these categories. It is therefore recommended that the company should use model in regular intervals. These intervals should be between one and two months.

When new components and suppliers are added to the supplier base, basic information regarding the component has to be entered to the ERP-system. If e.g. unit cost is set to zero, it will greatly affect both the current and the suggested classification model, and therefore not give a satisfying result. Since new components can be added without running the classification model, a default class should be specified to ensure that the components are treated reasonably.

8.5.2 Long-term recommendations

The long-term recommendations focus on how to implement a new model for classification at the company, and how the suggested model can be further developed.

The main long-term recommendation for this thesis is to implement a new classification model based on several criteria according to the suggestions that have been given in this thesis, see Section 7.1. How to classify supplied components is a tactical decision that has a major impact on how the company performs, but an implementation would greatly affect some functions within the company, implying that it should not be rushed. Such an implementation has major impact on the purchasing and production processes and should therefore be carried out sequentially i.e. one production site at time to be able to evaluate the result. This is possible since it is the purchasing function located at each site that is responsible for component availability, and therefore the allocation of sourcing resources between the sites is not equally affected.

A suggestion related to the classification is to further develop the criterion related to degree of standardization. Unit cost might not be an optimal approximation, and another parameter can be used in the classification model in order to get a

better result than presented in this report. This new parameter would then replace unit cost as the third parameter in the suggested model. One example for capturing the degree of standardization can be a ranking system where the components are graded after how easy they are to source. The different categories can for example be standard electronics, complex manufactured components, engineered components and single sourced components.

Sustainability is an important area that should be a part of all processes within a company and even the purchasing processes has to take this factor under consideration. Environmental, social and economic sustainability should all be addressed to attain a sustainable organization. Since the purpose with the classification model is to assign appropriate levels of safety stock, sustainability as a parameter is not that relevant. The area should preferably be addresses in addition to the classification model, e.g. when choosing which new components to purchase, or which suppliers to cooperate with.

Aside from implementing a new classification model, the main subject that is recommended to investigate further is related to the service levels set by The Company. The service levels that are used today within the company can be evaluated and challenged, in order to find suitable levels for all the generated classes. Since the classes are differentiated by the service levels, the classification model will be even more beneficial if appropriate service levels are used for the classes. As mentioned in Section 8.2, it is recommended to use another method than S_1 to calculate the service level and the safety stock, which takes the order quantity into account.

Another research area closely related to the service levels is the safety stock levels. The formula that is used today for calculating safety stock levels can advantageously be challenged from a theoretical perspective. By doing so, it will be possible to lower the capital employed in the component inventory, without compromising the customer satisfaction.

In addition to the methods presented in this thesis, software for inventory control can also be evaluated. Such software entails less user control and a greater investment that must be weighed against the requested results.

8.6 Academic contribution

A contribution to science that this thesis has provided is the overview over the main methods within the classification area. A great number of classification

methods do exists, but the ambition for this thesis has been to describe those who have different origin and are therefore dissimilar in execution.

Since this thesis is based on the situation and circumstances for one specific company, The Company, the possibility to make the result general is limited. For organizations in similar environment with similar characteristics for their incoming material, the result can be useful since many of the discussions and reasoning found in this report can be valid.

Even if the situation for a company is not similar to the situation of The Company, this thesis can still be used as a starting point when developing a new classification model, alternatively redesign an existing model. The method for identifying possible parameters, selecting parameters and even selecting a suitable classification method is considered to be applicable for other organizations with the ambition to create or redesign a classification model.

9 References

Arbnor, I. & Bjerke, B., 2008. *Methodology for Creating Business Knowledge.* 3rd edition ed. California: SAGE Publications Ltd.

Axsäter, S., 2006. *Inventory Control.* 2nd edition ed. New York: Springer.

Bergman, B. & Klefsjö, B., 2012. *Kvalitet - från behov till användning.* Upplaga 5 ed. Lund: Studentlitteratur.

Bose, C. D., 2006. *Inventory Management.* 1st edition ed. New Delhi: Prentice-Hall of India Pvt. Ltd..

Chu, C.-W., Liang, G.-S. & Liao, C.-T., 2008. Controlling inventory by combining ABC analysis and fuzzy classification. *Computers & Industrial Engineering,* 55(4), pp. 841-851.

Ernst, R. & Cohen, M. A., 1990. Operations related Groups (ORGs): A Clustering Procedure for Production/Inventory Systems. *Journal of Operations Management,* 9(4), pp. 574-598.

Flores, B. E., Olson, D. L. & Dorai, V. K., 1992. Management of Multicriteria Inventory Classification. *Mathematical and Computer Modelling,* Volume 16, pp. 71-82.

Flores, B. E. & Whybark, C. D., 1986. Multiple criteria ABC analysis. *International Journal of Operations and Production Management,* 6(3), pp. 38-46.

Gammelgaard, B., 2004. Schools in logistics research? A methodological framework for analysis of the discipline. *Internationel Journal of Physical Distribution & Logistics Management,* 34(6), pp. 479-491.

Gorunescu, F., 2011. *Data Mining- Concepts, Models and Techniques.* Volume 12 ed. Berlin: Sringer.

Guvenir, A. H. & Erel, E., 1998. Multicriteria inventory classificatio using a generic algorithm. *European Journal of Operational Research,* 105(1), pp. 29-37.

Hopp, W. J. & Spearman, M. L., 2011. *Factory Physics.* Third Edition ed. Long Grove,Illinois: Waveland Press Inc..

Höst, M., Regnell, B. & Runeson, P., 2006. *Att genomföra examensarbete.* 1:6 ed. Lund: Studentlitteratur.

Kovács, G. & Spens, K. M., 2005. Abductive reasoning in logistics research. *International Journal of Physical Distribution & Logistics Management,* 35(2), pp. 132-144.

Lumsden, K., 2006. *Logistikens grunder.* 2:a upplagan ed. Lund: Studentlitteratur.

Martin, W. & Stanford, E. R., 2007. A methodology for estimating the maximum profitable turns for an ABC inventory classification system. *IMA Journal of Management Mathematics,* Volume 18, pp. 223-233.

MathWorks, 2014. *mathworks.se.* [Online]
Available at: http://www.mathworks.se/help/stats/k-means-clustering.html#brah7f1-1
[Accessed 06 05 2014].

MathWorks, 2014. *mathworks.se.* [Online]
Available at: http://www.mathworks.se/help/stats/kmeans.html
[Accessed 16 05 2014].

Mattsson, S.-A., 2003. Några synpunkter på att reducera kapitalbindning. *Bättre Produktivitet,* Volume 1.

Mattsson, S.-A., 2005. *lagerstyrningsakedemin.se.* [Online]
Available at: http://www.lagerstyrningsakademin.se/Rapporter/LS32.pdf
[Accessed 31 03 2014].

Medasani, S., Kim, J. & Krishnapuram, R., 1998. An overview of membership function generation techniques for pattern recognition. *International Journal of Approximate Reasoning,* 19(3-4), pp. 391-417.

Nahmias, S., 2009. *Production and operations Analysis.* Sixth edition ed. New York: Mc Graw Hill.

Ng, W. L., 2007. A simple classifiier for multiple criteria ABC analysis. *European Journal of Operation research,* Volume 177, pp. 344-353.

Nilsson, B., 2014. *Att starta processen....* Lund, Division of Production Management, Department of Industrial Management and Logistics, Lunds University.

N, N., 2014. *Director Supply Chain Management* [Interview] (27 01 2014).

N, N., 2014. *Supply Chain Developer* [Interview] (19 03 2014).

N, N., 2014. *Supply Chain Developer* [Interview] (06 05 2014).

Nydick, R. L. & Hill, R. P., 1992. Using the Analytic Hierarchy Process to Structure the Supplier Selection Procedure. *International Journal of Purchasing and Materials Management,* 28(2), pp. 31-36.

Partovi, F. Y. & Anandarajan, M., 2002. Classifying inventory using an artificial neural network approach. *Computers & Industrial Engineering,* 41(4), pp. 389-404.

Ramanathan, R., 2006. ABC inventory classification with multiple-criteria using weighted linear optimization. *computers & Operations research ,* Volume 33, pp. 695-700.

Saaty, T. L. & Vargas, L. G., 2012. *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process.* 2nd edition ed. New York: Springer.

Simangunsong, E., Hendry, L. C. & Stevenson, M., 2012. Supply-chain uncertainty: a review and theoretical foundation for future research. *International journal of Production Research,* 50(16), pp. 4493-4523.

Skärvad, P.-H. & Olsson, J., 2008. *FöretagsEkonomi 100.* Upplaga 14 ed. Malmö: Liber.

Teunter, R. H., Babai, M. Z. & Syntetos, A. A., 2010. ABC Classification: Service Levels and Inventory Costs. *Production and Operations Management,* 19(3), pp. 343-352.

The Company, 2012. *Annual Report.* [Online].

Van Weele, A., 2009. *Purchasing and Supply Chain Management.* 5th edition ed. Stamford, Connecticut: Cengage Learning EMEA.

Warren, M. & Standford, R. E., 2007. A methodology for estimating the maximum profitable turns for an ABC inventory classification system. *IMA Journal of Management Mathematics,* Volume 18, pp. 223-233.

Yin, R. K., 2009. *Case Study Research - Design and Methods.* Fourth Edition ed. Thousand Oaks: SAGE Publications Inc..

Yin, Y., Kaku, I., Tang, J. & Zhu, J., 2011. *Data Mining - Concepts, Methods and applications in Management and engineering Design.* 1st edition ed. London: Springer.

Zadeh, L. A., 1965. Fuzzy Sets. *Informantion and Control,* 8(3), pp. 338-353.

Zhou, E. & Khotanzad, A., 2007. Fuzzy classifier design using genetic algorithms. *Pattern Recognetion,* 40(12), pp. 3401-3414.

10 Appendix

A.   Interview guide for benchmark (in Swedish)

Intervjutyp: Semi- strukturerad
Tid:
Plats:
Intervjuobjekt:

Introduktion
- Presentation av studenter.
- Presentation av projektet.
- Presentation av syftet med intervjun.

Bakgrund
- Vad har du för titel?
- Vilka är dina primära arbetsuppgifter?
- Hur länge har du jobbat här?
- Hur länge har du haft dina nuvarande arbetsuppgifter?

Allmänt om arbete kring inköp
- Arbetar ni med ABC-klassificering av era leverantörer?
- Arbetar ni med ABC-klassificering av de komponenter som ni köper in?
- Använder ni klassificering för alla de komponenter som ni köper in eller bara en del av dem? Varför bara en del? Hur väljer ni ut den delen?
- Vad är huvudsyftet med att ni utför er klassificering? Vad använder ni ert klassificeringsresultat till?
- När använder ni resultatet?
- Har ni en modell som hjälper er att klassificera eller sker klassificeringen manuellt?
- Hur ofta uppdaterar ni er klassificering?
- Vad tycker du är det mest väsentliga med er klassificeringsmodell?

Klassificeringens uppbyggnad
- Bygger er klassificering på volymvärde, vilket är den vanligaste parametern för klassificering (single-criterion classification) eller bygger er klassificering på någon annan parameter? Vad ser ni för fördelar med detta?
- Använder ni flera kriterier vid klassificering (multi-criteria classification)? Vad ser ni för fördelar med det?
- Hade ni velat använda fler eller andra kriterier än de som ni använder idag? Vad hade det medfört för fördelar?
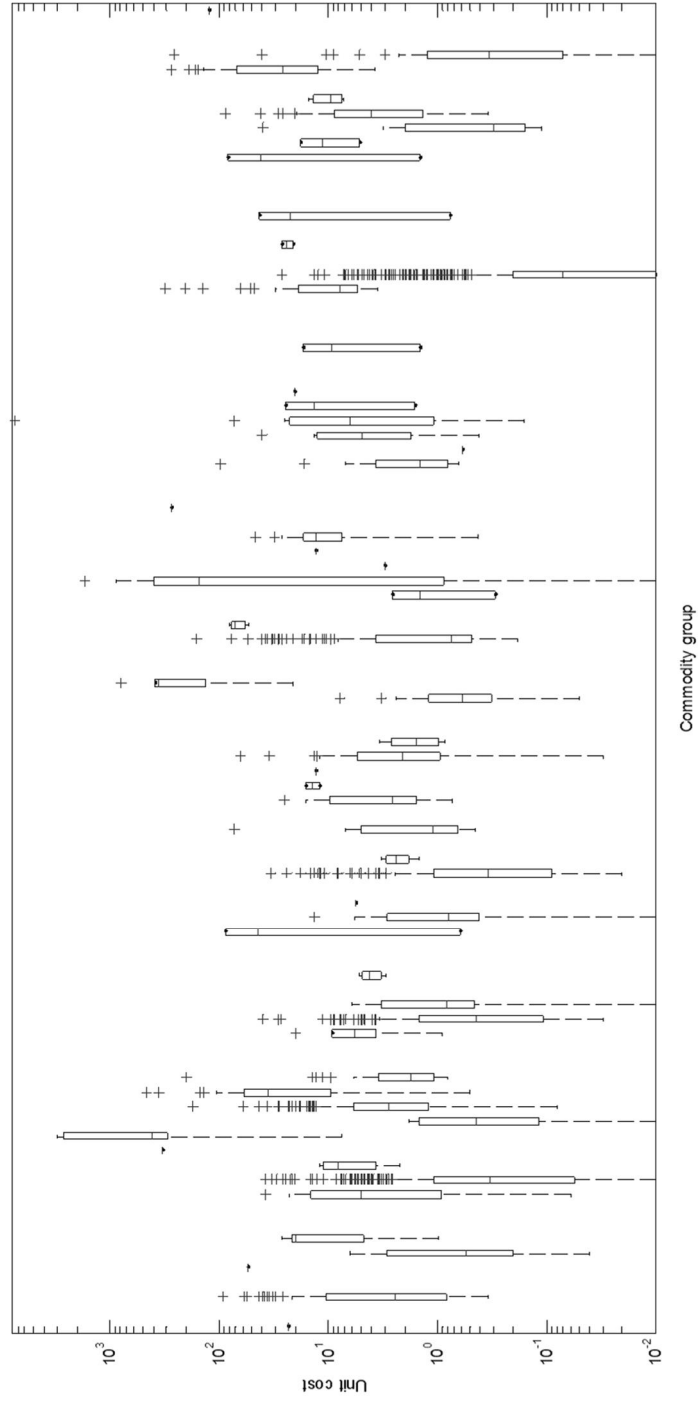
Allmänt om klassificering
- Vilka kriterier är viktigast att ha i åtanke vid klassificering?
- Vad är det mest väsentliga med en klassificeringsmodell?
- Är det viktigt att man förstår hur klasserna beräknas eller är det viktigare att klassindelningen blir bra?
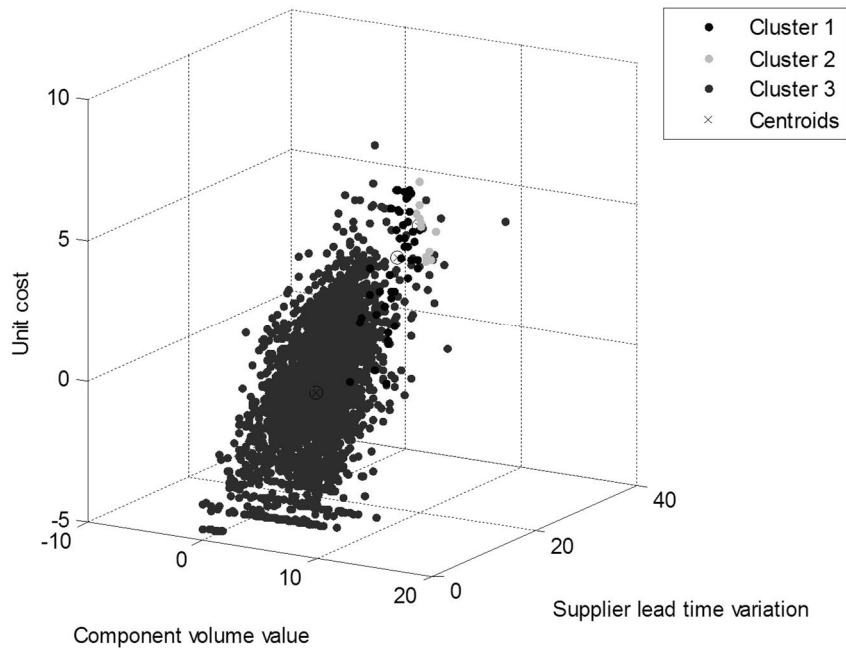
B. Cause effect diagram
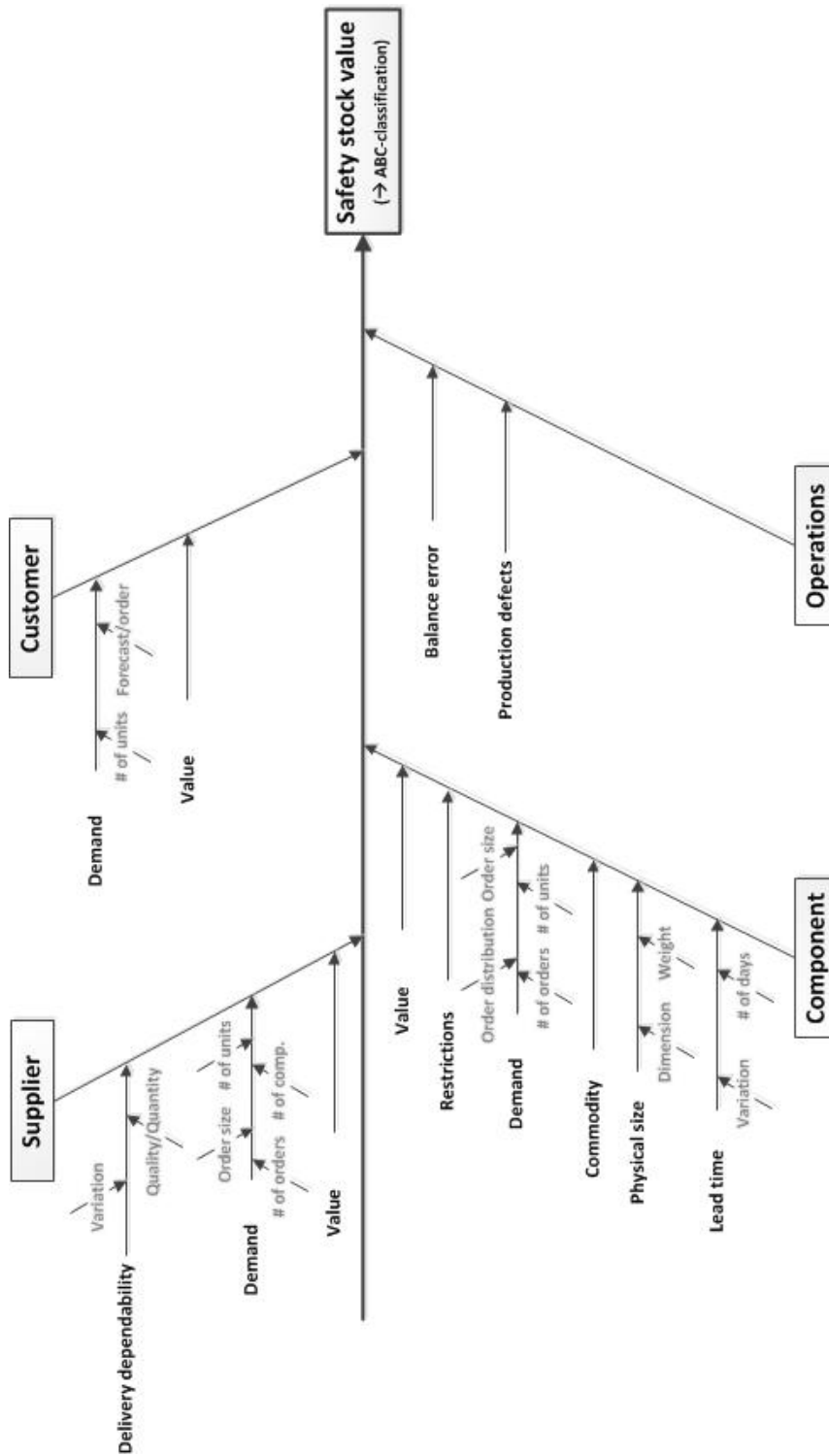
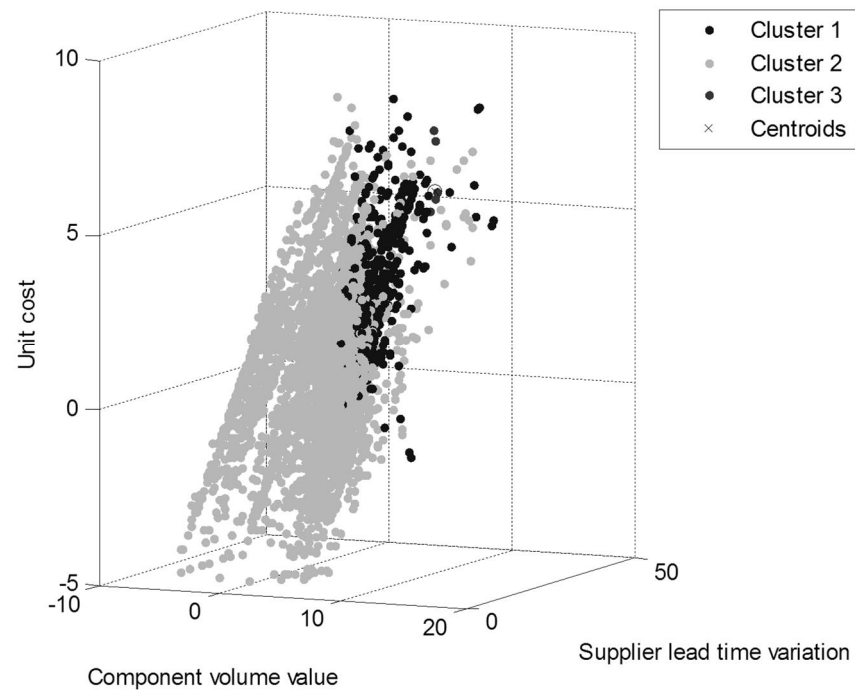## C. Commodity group boxplot

D. Cluster analysis

Result of k-mean cluster analysis (forecast components)

Result of k-mean cluster analysis (order components)

MatLab code for k-mean cluster analysis

```
% Create k-mean clusters
opts = statset('Display','final');
[idx,c]=
kmeans(z,3,'Distance','city','Replicates',100,'Options',opts)
;

% Plot the clusters
plot3(log(z(idx==1,1)),z(idx==1,2),log(z(idx==1,3)),'b.');
hold on ;
plot3(log(z(idx==2,1)),z(idx==2,2),log(z(idx==2,3)),'g.');
plot3(log(z(idx==3,1)),z(idx==3,2),log(z(idx==3,3)),'r.');

% Plot the cluster centroids
plot3( log(c(:,1)),c(:,2),log(c(:,3)),'kx');
plot3( log(c(:,1)),c(:,2),log(c(:,3)),'ko');

% Description
xlabel('Component volume value')
ylabel('Supplier lead time variation')
zlabel('Unit cost')
legend('Cluster 1','Cluster 2','Cluster 3','Centroids')

grid on
hold off
```