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The School of Industrial Engineering and Management
The Department of Innovation Management
Master's thesis

Warranty prediction using Weibull simulation

Examiners: Professor Timo Kärri and
Professor Andrzej Kraslawski

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Salla Saraneva

ABSTRACT

Author: Salla Saraneva

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The main objective of this master's thesis is to examine if Weibull analysis is suitable method for warranty forecasting in the Case Company. The Case Company has used Reliasoft's Weibull++ software, which is basing on the Weibull method, but the Company has noticed that the analysis has not given right results. This study was conducted making Weibull simulations in different profit centers of the Case Company and then comparing actual cost and forecasted cost. Simulations were made using different time frames and two methods for determining future deliveries. The first sub objective is to examine, which parameters of simulations will give the best result to each profit center. The second sub objective of this study is to create a simple control model for following forecasted costs and actual realized costs. The third sub objective is to document all Qlikview-parameters of profit centers. This study is a constructive research, and solutions for company's problems are figured out in this master's thesis.

In the theory parts were introduced quality issues, for example; what is quality, quality costing and cost of poor quality. Quality is one of the major aspects in the Case Company, so understanding the link between quality and warranty forecasting is important. Warranty management was also introduced and other different tools for warranty forecasting. The Weibull method and its mathematical properties and reliability engineering were introduced.

The main results of this master's thesis are that the Weibull analysis forecasted too high costs, when calculating provision. Although, some forecasted values of profit centers were lower than actual values, the method works better for planning purposes. One of the reasons is that quality improving or alternatively quality decreasing is not showing in the results of the analysis in the short run. The other reason for too high values is that the products of the Case Company are complex and analyses were made in the profit center-level. The Weibull method was developed for standard products, but products of the Case Company consists of many complex components. According to the theory, this method was developed for homogeneous-data. So the most important notification is that the analysis should be made in the product level, not the profit center level, when the data is more homogeneous.

TIIVISTELMÄ

Author: Salla Saraneva

Työn nimi: Takuuvarauksen ennustaminen Weibull simulaatiolla

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Työn päätarkoituksena on tutkia, onko Weibull analyysi soveltuva työkalu takuuvarausten ennustamiseen Case yrityksessä. Yritys on käyttänyt Reliasoftin Weibull++ ohjelmistoa, joka perustuu Weibull metodiin. On kuitenkin huomattu, että metodi ei ennusta kustannuksia oikein. Tutkimus on toteutettu tekemällä simulaatioita Weibullin avulla ja vertailemalla Weibullin antamia kustannuksia toteutuneisiin kustannuksiin. Työssä tutkittiin eri aikajaksoja ja kahta erilaista tapaa ottaa huomioon tulevaisuuden toimitukset. Työn tarkoituksena on myös analysoida, mitkä simulaation parametrit antavat parhaan tulokset kullekin tulosyksikölle. Työn muina tavoitteina oli rakentaa yksinkertainen malli ennustettujen ja toteutuneiden takuukustannusten seuraamiseen. Tavoitteena on myös dokumentoida käytettävät Qlikview-parametrit. Työ on konstruktiivinen tutkimus, jossa pyritään löytämään ratkaisu yrityksen ongelmaan.

Työn teoriaosissa käsitellään laatua yleisesti, laatukustannuksia ja huonon laadun kustannuksia. Laatu on yksi yrityksen tärkeimmistä alueista, joten laadun ja takuukustannusten välinen linkki on hyvä ymmärtää. Työssä käsitellään myös takuujohtamista ja erilaisia muita takuukustannusten ennustamiseen kehitettyjä menetelmiä. Weibull metodi ja siihen liittyvät matemaattiset ominaisuudet esitellään yleisesti. Laatuun ja takuujohtamiseen liittyvä luotettavuustekniikka näkökulma otetaan myös esille.

Työn keskeisin tulos oli, että Weibull analyysi ennusti tulosyksiköille liian suuria takuukustannuksia, varausta laskettaessa. Tosin, osassa tulosyksiköistä ennustettu kustannus oli liian pieni. Menetelmä toimi paremmin suunnittelutarkoitukseen. Syy liian suuriin ennustettuihin kustannuksiin on se, että menetelmä ei huomioi laadun paranemista tai laadun huononemista lyhyellä aikavälillä. Toinen syy menetelmän toimimattomuuteen on, että esimerkkiyrityksen tuotteet ovat monimutkaisia ja ne koostuvat monista eri komponenteista. Tarkastelu tehdään myös tulosyksikkötasolla. Teorian mukaan metodi on kehitetty homogeeniselle datalle. Jos analyysi tehtäisiin tulosyksikkötason sijaan tuotetasolla, tulokset olisivat tarkempia, koska data on silloin homogeenisempää.

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LIST OF SYMBOLS

β	shape parameter
η	scale parameter
γ	location parameter
v	time
i^{th}	population
p_i	portion or mixing weight for the i^{th} population
t	duration of the new mission
T	duration of the successfully completed previous mission

1 Introduction

1.1 Background

This master's thesis relates to the warranty cost forecasting in the Case Company. The Case Company has had problems in its warranty prediction process, so solutions are sought by this master's thesis. Even though topics are warranties and forecasting, the quality aspect also relates closely to this thesis. The main objective of this thesis is to study is the Weibull method suitable method for warranty forecasting in the Case Company.

The target of the Case Company is to provide quality products and services. Quality is one of the most important aspects and mentioned in the company's strategy. Furthermore, following and calculating the cost of poor quality has been one of the top topics in the Case Company in recent years. So the research of this master's thesis is natural continuum of improving quality. Even though the target of this research is not to improve the quality of products and services, but it can be said, that the quality of the internal processes will be improved by this research and a workable quality process will also affect the result in a positive way.

The Company has used the Reliasoft Weibull++ software for warranty forecasting, but they have noticed that the Weibull analysis does not work properly or in other words, the forecasted costs by the method have been too small compared to the actual costs. There is a doubt, that the used time period is too long, so two time periods will be tested, as well as, for analysis, future deliveries are needed, so two kinds of method for future deliveries will be tested. The first sub objective is to study, which parameters will give the best results in the simulations.

The Case Company has factories in many continents and countries and Company wants that costs would be followed in the same way in the every factory. The second sub objective of this master's thesis is to create a harmonized control model for controlling forecasted and actual warranty costs in the Case Company. The Company uses a database called Qlikview, where data will be taken for the Weibull analysis, so the third sub objective is to document the right Qlikview -parameters of the factories and the profit centers. The Case Company will be handled anonymously and exact numbers will not be introduced.

This topic is very important for the Case Company. One hand they want to forecast and budget the future feedback costs correctly and make a right provision for the future feedback-costs. On the other hand, the solution of this research can be that the Weibull method is not suitable or the method does not give an exact enough forecasting. So one solution could be that the Case Company will abandon this method.

1.2 Research questions and limitations

The main objective of this master's thesis is to examine the suitability of the Weibull method for warranty forecasting in the Case Company. The objectives of this master's thesis are divided into one main research question and three sub questions as follows:

Is the Weibull method a suitable method for warranty forecasting in the Case Company?

-*Which parameters will give the best results in the simulations?*

-*What would be a suitable control model for comparing actual warranty costs and forecasted warranty costs?*

-*What are the Qlikview-parameters of each profit center?*

The main research question is studied by making simulations using different parameters, such as, time frame and future deliveries. The first and the second sub questions are based on findings of the first main research question. The third sub question is to determine and document the Qlikview -parameters of each profit center.

The objective is to test suitability of the Weibull method. If the method does not work, developing a new one is not a task of this master’s thesis. Internal quality of the Case Company is studied. Improving quality or reliability of products or services is not a target. Quality and reliability will be studied in the theoretical parts, because the both subjects are linking to this research.

One limitation, which can affect the result is, that when researching a provision, only the first 12 months will be examined instead of 42 months, because data is only available for the first 12 months. And also only the year 2013 will be examined.

1.3 Methods and data

This research is a constructive research. The object of a constructive research is to find an innovative solution for a concrete, real-world problem and it is solved by an implemented new construction. A theoretical background and examples create a basis for a constructive study. A constructive research consists of elements as in the figure 1. Real-world problem, a practical functioning of the solution, a theoretical link and a theoretical contribution of the research will contribute to the construction or the solution of the problem. The research is implemented step-by-step. In the first step, the problem and the target of the research and the research question should be determined. The second step is to understand the research area practically and theoretically. The third step is to find an innovative solution or an idea and develop a problem solving construction. The fourth step is to implement the solution and test how it works in practice. The fifth step is to discuss the scope of applicability of the solution and the last step is to identify and analyze the theoretical contribution. (Lukka 2014;Kasanen et al. 1991, 305-307) The constructive of this research is to find the solution or a suggestion for the questions, is the Weibull model suitable for the Case Company?

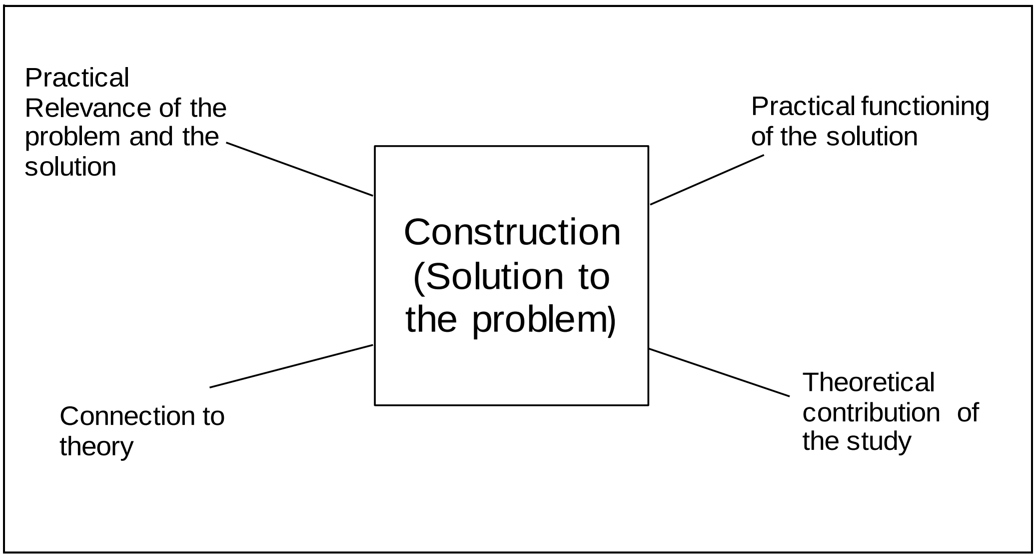

Figure 1. Elements of a constructive research approach

This research will be carried out by making simulations using the Reliasoft – Weibull++ software. The research is implemented by researching forecasted costs for the year 2013. The year 2013 was selected, because it is over and the actual feedback costs are known. Now it is meaningful to compare forecasted cost of the year 2013 and the actual, realized costs of the year 2013. The examined time frames are 42 months between June 2009 and November 2012 and 24 months between December 2010 and November 2012. In case of one profit center, 18 months will be examined. The time frame in that regard is from June 2010 to November 2012. The method is based on a historical data, so when the last month of the simulation is November 2012, the forecasting of feedbacks will be for December 2012, for January 2013 and so on.

In a pilot project, simulations are first made for the factories/profit centers in Finland. The findings will be tested in two other factories/profit centers in South Europe and America. Data has in a key role in simulations. The data is from the Case Company and it can be assumed, that the data is correct and usable without any editing. The Weibull++ software estimates the parameters of the different distributions and the software automatically gives a suggestion, which distribution would be the most suitable, so in this master's thesis the suggestion given by Weibull++ software is trusted.

1.4 Structure

The Master's thesis consists of two parts: theoretical and empirical as in the figure 2. The chapters 2, 3 and 4 are handling theory and the chapters 5, 6, 7 and 8 are handling the empirical parts. The purposes of the first theory part: *Quality thinking* is first and foremost, describe the background of quality costing and cost of poor quality and furthermore, clarify the definition of quality. The purpose of the second theory part is to provide understanding of the warranty concept, and a warranty management. Another important part is the introduction of tools for warranty prediction, because the Case Company wants to know what kinds of tools are available. The third theory chapter: the *Weibull method* provides information about the Weibull method in a mathematical way, but also introduces reliability engineering, because it relates closely to quality and a warranty management. The fifth chapter is the first empirical chapter. Its purpose is to introduce the Case Company, even if the Case Company will be handled anonymously during the whole study. Problems and the objectives will be introduced more specifically than in the introduction. The sixth chapter handles simulation through a general example and as well as all simulations of each profit center/factory. The seventh chapter is handling the results and the analysis based on results of the simulations. Some notification of the Weibull analysis in the Case Company is also handled. The conclusions are in the eighth chapter.

Chapter	Title	Contents
1	Introduction	Background, Research questions and limitations, Methods and data and structure of the study
2	Quality thinking	Definition of quality, Perspective of quality, Quality costing and Elements of Cost of Poor quality
3	Warranty management	Concept and role of warranty, Classification of warranties, Definition of Warranty management, Warranty cost analysis, Feedback-process, Toold for warranty prediction, Uncertainty in Forecasting
4	Weibull method	Background of Reliability Engineering, Weibull distribution, Weibull statistical properties and Parameter estimation and data classification
5	Case Company	Company presentation, Problem description and objectives, Process description
6	Simulations of different factories	Presentation of software and simulation, Simulations in Finland, South Europe and America and presentation of follow-up model
7	Results and Analysis	Selected parameters in each profit centers, Impact of distribution, Notification of Weibull method in Case Company
8	Conclusions	Conclusions of the study

Figure 2. The structure of this study

2 Quality thinking

2.1 What is quality?

Many managers and researcher have tried to define quality universal way and discovered how difficult it is. Quality is an elusive concept and it includes many meanings and interpretations. It is important to understand differences between different definitions (Seawright & Young 1996, 107). Concept of quality has been researched throughout history and it is still one of the topic subjects in companies and academic world. Quality has been defined various as value, conformance of specifications, conformance of requirements, fitness for use and meeting customers' expectations (Reeves & Bednar 1994, 419-420).

According to SFS ISO 8402-Standard (1988): Quality is all features and attributes of a product or service, whereby a product or service fulfills assumed or set needs.

Grosby (1979, 1) highlights the thought that, if producing quality products, it doesn't cost anything. If manufacturing makes unquality products, it costs money to do rework and it pays to fix them. All actions that involve not doing things right at the first time cost money. Juran (1951) summarized in his concept of the cost of poor quality that all costs would disappear, if there were no quality problems. This though is similar than Grosby's.

Feigenbaum (1991, 7) has described quality as a customer determination, not engineer's or a marketing determination. It based upon customer's actual experiment of product or service, measured against customer's requirements and that requirement is totally subjective.

According to Juran & Godfrey (1998, 2.1-2.3) there are many meanings of the word "quality", but there are only two critical importances to managing quality: Quality means those *features of products,* which provide customer satisfaction and meet customer needs. Second one is: *Quality means freedom from deficien-*

cies. If work must be done over again, it is causing errors and result is customer dissatisfaction. Meaning of quality relates to costs and can be said that higher quality usually costs less, even though common misunderstood is that higher quality product costs more.

2.2 Perspective of quality

The definition of quality's five different approaches has been identified by Garvin (1984, 25). Organization has not only one view of quality. They need different views in different departments. The following has been listed five approaches of different point of view.

1) The transcendent approach: Quality is described as a condition of overall excellence. The view of transcendent quality is based upon individual customer preference. This approach is too indefinite for practical purposes (Seawright &Young 1996, 108). According Garvin (1987, 25) quality can only be identified when it is experienced, like beauty, but not be measured.

2) The product-based approach: The view is that quality is exact and measurable variable. This approach means that differences in quality reflect differences in quantity of some ingredient or attribute possessed by a product. According to this thinking, higher quality can only be obtained at higher cost, so higher-quality goods will be more expensive.

3) User-based definition: Individual consumers have different needs and that kind of product, which will satisfy their preference best, seems to be the highest quality product. This is a personal view of quality and highly subjective.

4) Manufacturing based definition: Focuses on the supply side and mainly deal with engineering and manufacturing practices. This approach identifies the consumer's interest in quality. Quality is a manner which simpli-

fies engineering and control of production. Idea of this approach is that improvements in quality leads to lower costs, preventing defects is less expensive than repairing or reworking.

5) Value-based definition: This approach leads idea further than manufacturing-based approach. Quality is defined in terms of costs and prices. This means that a quality product is one that provides performance at an acceptable price. So the most expensive product is not necessarily the best. "Quality means best for certain customer conditions. These conditions are (a) the actual use and (b) the selling price of the product" (Feigenbaum 1991, 9)

Multiple definitions are needed to capture the complexity of quality and for firms address quality issues that changes product to move through various stages from design to the market (Sebastianelli & Tamimi 2002, 442-44)

In the figure 3 has been plotted each definition of quality on the two dimensions of internal to external and objective to subjective. Evaluation of transcendent quality is based upon individual customer preference and it is external to the company. Manufacturing-based definitions of quality are objective and internal. Product-based quality is external and objective, it also depends on customer preference. User-based definitions are subjective and external as also value-based definitions. (Garvin 1984, 25; Seawright & Young 1996, 110)

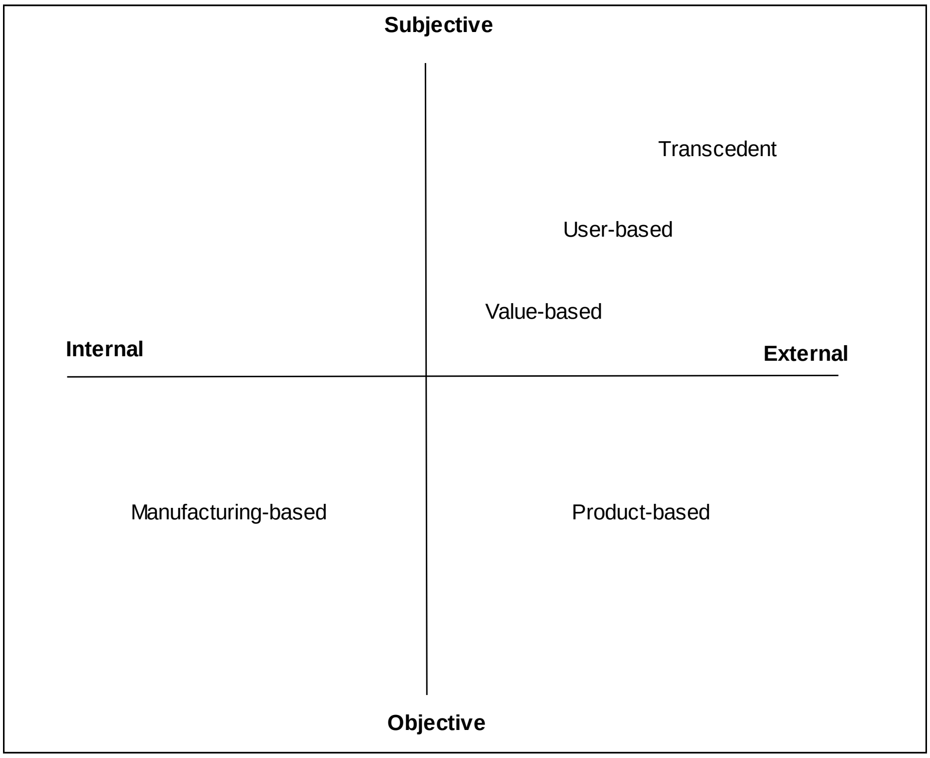

Figure 3. Two dimensions of quality (Seawright & Young 1996, 110)

Many times the definitions of quality belong into one of the categories, which mentioned above. It depends on the perspective of reviewer. For example marketing people typically take a user-based or product-based approach point of view. Manufacturing people usually take a different approach. This will cause conflict and it can cause breakdowns in communication. It is self-evident that they should regard different perspective of quality, not focus on only one approach or perspective. (Garvin 1984, 28)

Into *multidimensional quality description* has been combined various aspects of product and service quality. Garvin (1979, 29-32) has combined many aspects of product quality into eight general dimensions, which are performance, features, reliability, conformance, durability, serviceability, aesthetics and perceived quality. Each dimension is independent and separate. One dimension can be ranked high for a product and other dimension can be low (Garvin 1984, 30). Parasunaman et al. (1991, 420-424) have identified five dimensions of service quality: tangibles, reliability, responsiveness, assurance and empathy.

The Malcolm Baldrige National Quality Award is based on seven areas of quality criteria: leadership, information and analysis, strategic quality planning, human resource development and management, management of process quality, quality of operational results and customer focus and satisfaction. (National Institute of Standards and Technology 1993 cited in Seawright & Young 1996, 110)

It is good to notice that in all three descriptions other single distributions are more important than others and also some distributions are more expensive to implement than others. Garvin's model is good planning tool in strategic level, when discussed, which distributions are important to company. The areas of Malcolm's model are not a single attributes. Organization should pay attention to all areas, because all distribution affects to quality of a product or service.

2.3 Quality costing

Quality cost concept was introduced by Juran in 1951. Since 1950 many researchers have written about different quality systems and interest for quality control systems has been increased. (Yang 2008, 175) Quality is a key area for customer value and it should be part of company's competitive strategy (Tsai 1998, 179)

Definition of cost of quality is widely used and misunderstood. Cost of quality is the cost of *not* creating a quality product or service. Incorrectly is thought that cost of quality is the price of creating a quality product or service. The cost of quality increases, when work is redone. (Christensen et al. 2007, 10)

Crosby (1965) has launched his own definition of cost of quality. He divided the cost of quality into four categories:
-Rework costs
-Scrap costs
-Warranty costs
-Quality control labor

In 1979 Crosby (101-107) launched a new dividend, where he divided cost of quality into three categories:
-Prevention costs
-Appraisal costs
-Failure costs

Feigenbaum's in 1943 launched model divides quality costs into four groups: prevention cost, appraisal cost, internal defect cost and external defect cost (Harrington 1999, 222). Later Faigenbaum (1991, 110) launched a new model, which divides first operating quality cost into costs of control and costs of failure of control. Costs of control are subdivided into prevention costs and appraisal costs. Costs of failure of control are subdivided into internal failure costs and external failure costs. This model is called PAF-model and it is widely used and spread model. This typology is commonly and nowadays accepted (Sower et al. 2007, 123) and the concept is still based on the same premises as in 1950s (Moen 1998, 334) and also Campanella (1999, 5) highlight this categorizing in his book: Principles of quality costs. Feigenbaum's (1991, 7) quality cost concept provides an excellent management tool. It is still applicable in quality-improvement activities and measures the effectiveness of the total quality system.

PAF-model is represented in the figure 4. **Prevention costs** incur when "avoiding a defect product reach the consumer". For examples quality engineering and employee quality training are prevention costs. **Appraisal costs** include the costs for maintaining company quality levels. Inspection, test and quality audits are examples of appraisal costs. (Feigenbaum 1991, 111-112)

The cost of the failure of control is caused when product does not meet quality requirements, and it can be measured by two segments: Internal failure costs and external failure costs. Internal failure cost includes the cost of unsatisfactory quality in the company, for example scrap, spoilage and reworked material. External failure cost includes cost of unsatisfactory quality outside the company, such as product-performance failures and customer complaints. External failure cost is the worst case for a company, because customer also notices it. (Campanella 1999, 4-5)

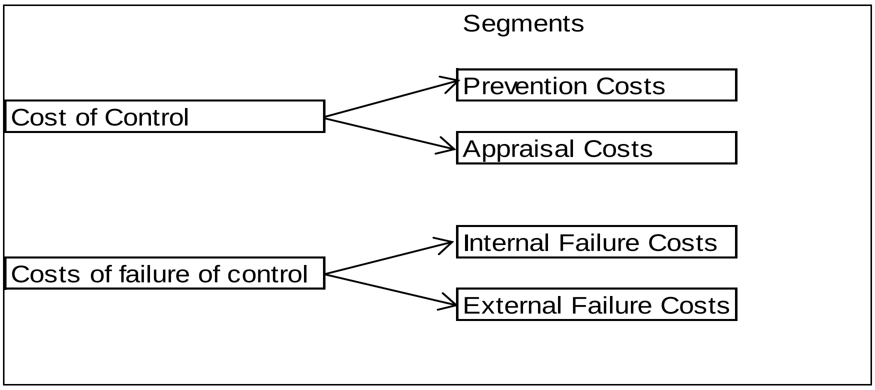

Figure 4. PAF-Model (Feigenbaum 1991, 111)

Two terms, Cost of Quality, CoQ and Cost of Poor-Quality, CoPQ are synonymous and both can be used to describe quality cost (Yang 2008, 177). According to Campanella (1999, 3), term cost of quality is more used and more familiar than cost of poor quality. It must be remembered that cost of quality includes more than just the cost of the quality organization. Harrington (1987, 5) has defined the poor-quality costs as "all cost incurred to help the employee do the job right every time and the cost of determining if the output as acceptable, plus any cost incurred by the company and the customer because the output did not meet specifications and/or customer expectations."

The purpose of a poor-quality-costs system is to "provide data for management and employees that can be used to identify improvement opportunities optimize the improvement effort effectiveness and measure progress". Cost of poor quality can't resolve quality problems of company, but it is useful tool for management. CoPQ helps understand the greatness of the quality problem and opportunities for improvement. (Harrington, 1987, 3, 8-9)

If there is need to manage and control quality costs, measuring is mandatory. Without measuring, information for decision making is hidden in business. Other reasons for measuring are: critical in profitability assessment, identifies quality problems, evaluate overall production costs and element for productivity improvement. Traditional managerial accounting systems are usually structured poorly to get the real cost of quality and make true profitability visible. This indicates that there are lots of potential for quality improvement. (Krishnan 2006, 78)

The company's key areas of waste are: material, capital and time, and time are the biggest cost. 20 – 30 % of revenue is expended for quality in the most American companies. According to Harry and Schroeder (2000) CoQ should be between 3-7 %, but usually it falls between 15-25 % (Yang 2008, 176). In the literature quality costs are reported to be between 5-30 % (Giakatis et al. 2001, 181)

2.4 Elements of cost of poor quality

Harrington has launched the elements of Poor Quality costs in 1987 and it is still useful model, which helps to understand elements of poor-quality costs. Harrington's model is based on PAF-model, but it includes a new perspective: indirect poor quality cost. Poor quality costs have been divided into two major divisions as in the table 5: Direct poor-quality costs and indirect poor-quality costs. *Direct poor-quality costs* can be found "in the company ledger and can be verified as by the company's accountants". It has been divided into Controllable poor-quality costs, Resultant poor-quality cost and Equipment poor-quality cost. The other major part- *Indirect poor-quality cost* defined as those costs not directly measurable in the organization's ledger, but part of the product life cycle. Indirect poor-quality cost consists of four subcategories: Customer-incurred PQC, Customer-dissatisfaction OQC, Loss-of-reputation PQC and Lost-opportunity PQC. (Harrington 1987, 6, 14, 128; Harrington 1999, 227)

I. Direct poor-quality cost
- A. Controllable poor-quality cost
  1. Prevention cost
  2. Appraisal cost
- B. Resultant poor-quality cost
  1. Internal error cost
  2. External error cost
- C. Equipment poor-quality cost

II. Indirect poor-quality cost
- A. Customer-incurred cost
- B. Customer-dissatisfaction cost
- C. Loss-of-reputation cost
- D. Lost-opportunity cost

Figure 5. Direct and Indirect poor-quality cost (Harrington 1999, 224)

Controllable PQC: Management can direct control these costs, because they can make sure that only customer acceptable product and services can be delivered to the customer. Controllable PQC are subdivided into two categories: prevention and appraisal costs. If company increases the preventive activities, company reduces the total error cost because the total number of errors is reduced. Appraisal activities do not reduce the total number of errors; it only detects a higher percentage of errors in the output before product is delivered to the customer. (Harrington 1987, 17)

Prevention costs will be caused to prevent errors. In financial viewpoint prevention cost is not cost at all; it is often called a cost-avoidance investment. (Harrington 1987, 14) Typical examples about prevention costs are: developing and implementing quality reporting systems, quality process control plan and quality-related training. (Harrington 1987, 14; Faigenbaum 1991, 111)

Appraisal costs: all costs expended to determine if an activity was done right (Harrington 1987, 15). These include the costs of incoming and source inspection/test of purchased material: in-process, final test, process audits and the costs of associated supplies and materials (Campanella 1999, 5).

Resultant poor-quality cost includes all the company-involved costs, which are results from error. Costs are direct losses to the company and costs are directly related to management decision made in controllable poor-quality cost category. Resultant poor-quality cost has been divided into internal error cost and external error cost. (Harrington 1999, 224-225)

Internal error cost: This category includes all cost, which are incurred by the company as a result of faults found before the product has been sent to the customer (Harrington 1987, 23). Sissonen (2008, 47) has found the following examples about internal error costs: scrap, reworking, retesting, replaced material, delays and shortages.

External error cost: External error cost would be caused, if company has sent a product to the customer, before the defective product has not been noticed by company (Harrington 1987, 24). External failure costs are the easiest find, measure and monitor. (Sissonen, 2008, 46) Examples are the cost processing customer complaints, customer returns, warranty claims and product recalls. (Campanella 1999, 5)

Equipment poor-quality cost is the last group of direct poor-quality cost. This group includes all equipment, which company has purchased to measure, accept, and control the product or service. This includes the cost of the equipment used to report quality data. Examples are computers and automated test equipment. This group does not include equipment used to make the product, only equipment for testing. (Harrington 1987, 25)

Customer-incurred cost is the first group of part of the indirect-poor-quality cost. It appears, when an output fails to meet expectations of customer. Typical examples about this group are: loss of productivity while equipment is down, travel cost and time spent to return defective product, repair cost after warranty period is over. (Harrington 1987, 227)

Customer-dissatisfaction cost is a binary thing. It has two options: customer can be satisfied or dissatisfied; seldom is anyone's opinion in between. The figure 6 illustrates customer-dissatisfaction PQC, where Y-axis is lost revenue and X-axis is product quality level. If viewing the old customer dissatisfaction quality costs curve, can be noticed that a sharp decreasing in lost revenue causes only small improvements in product quality. This curve proves a binary classification of satisfaction in the customer's mind. The curve becomes almost flat, even though product quality level increases. When customer gets better product their expectations will change. In the figure 6, the old customer dissatisfaction curve will move towards the new customer curve. In the new curve, the lost revenue is still same, even though the product quality level has improved. This means that customer's expectations are changing. (Harrington 1987, 139)

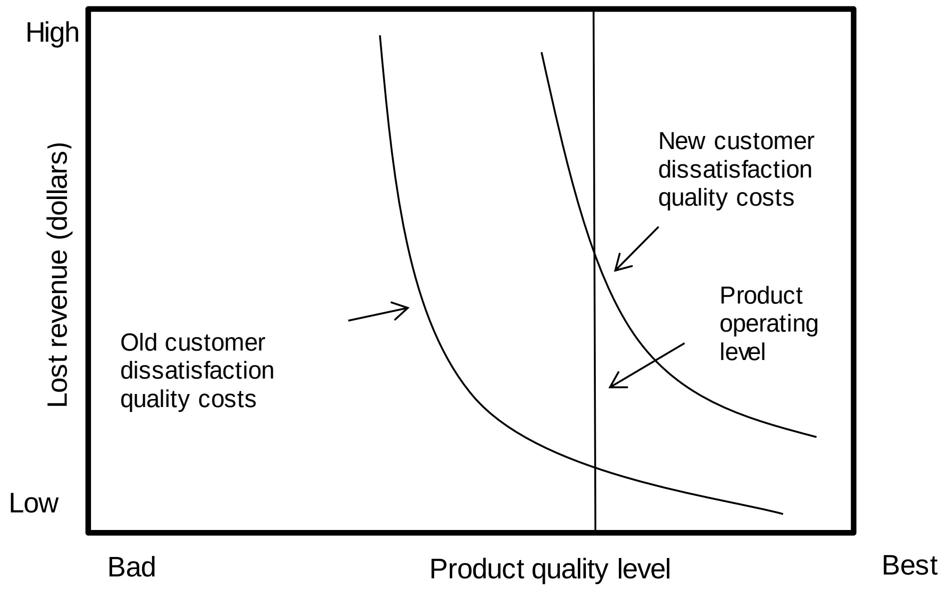

Figure 6. Customer-dissatisfaction costs

Loss-of-reputation cost is even more difficult to measure than two previous categories. The loss of a good reputation reflects the customer's attitude toward a company rather than toward an individual product line. If customer is dissatisfied for one product of a company, customer's opinion of whole company can change. That's why it may be reasonable to distribute and group products under different trade names based on expected performance. (Harrington 1987, 146; International Academy for Quality 2000, 142)

Lost-opportunity cost relates to money that company has not ever gotten, but company has lost, because the organization has not been taking advantage of an opportunity. For example case, where company loses contract to the competitor or customer, who turns away to competitor. (Harrington 1999, 228)

Hidden quality costs

The CoPQ can be separated in visible and invisible costs. According Krishnan (2006, 79) only little amount of costs can be seen and rest of costs are under the water as in the figure 7. Less visible costs can be difficult to see, recognize and measure in the company. Only the costs that are visible is taken consideration when talking about failure costs. The average European manufacturing cost of poor quality is about 15 to 25 percent of turnover. In the service sector or in some public sector organizations the amount can be even 40-50 percent. The hidden costs can be huge, between three and ten times the visible costs and unfortunately, many business decisions are made based on only the information from the visible costs.

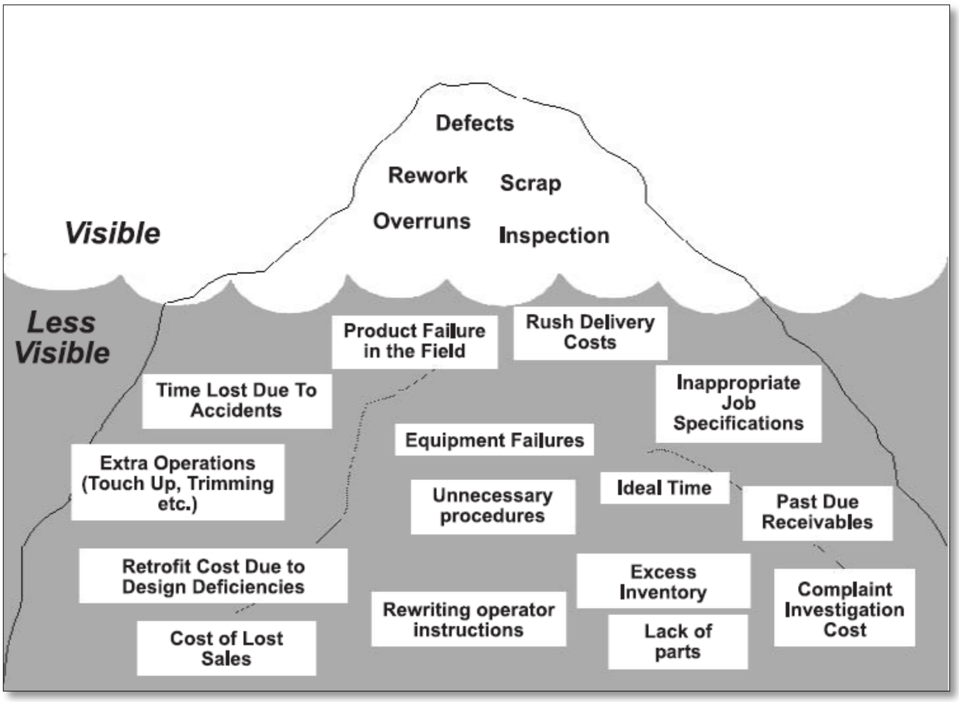

Figure 7. The Iceberg-model (Krishnan 2006, 84)

3 Warranty management

3.1 Concept and role of warranty

Warranty is a contractual agreement between seller and buyer, and it comes into effect when seller sales the product. This contract is the security for buyer if performance of product is unsatisfactory. Warranty management and different warranties have been much studied by researchers. (Blischke et al. 2011, 19) A warranty may be stated implicit or explicitly. Briefly, the warranty's purpose is to establish liability between manufacturer and seller in the case that an item fails. When an item, in properly used, is not able to perform its intended function satisfactorily, it is said to fail. (Murthy 2006, 134)

There are many applications and purposes of product warranty from many diverse disciplines: The following is a list of the most important issues of different fields:

-Historical
-Legal (buyer's rights, product liability)
-Economic (market equilibrium, social welfare)
-Consumerist (consumer protection)
-Engineering (design, manufacturing, quality control)
-Statistics (data-based reliability analysis)
-Accounting (tracking of costs)
-Marketing (use of warranty as a marketing tool)

Warranty has three perspectives. The buyer's perspective is different from that of the manufacturer. Third perspective is society. Warranty is dealt with many groups for example legislators, the courts and public policy decision-makers from a societal point of view. (Blischke 2011, 20)

3.2 Classification of warranties

Implied warranties are created by stated law. These kinds of warranties are unspoken and unwritten promises and they are based on the common law principles. Implied warranties are divided into two categories: implied warranty of merchantability and that of fitness. Briefly, first means that the item will works what it is supposed to be work and nothing is wrong with it. Second one means that it is promise that the item will be suitable for particular purposes. (Blischke et al. 2011, 21)

Express warranty is an agreement between the contract seller (manufacturer) and the buyer of a good. Seller promises to replace or repair the product or component failed of the product for specific time period. (Blischke et al. 2011, 21)

Other way to classify different warranty types is to use dimensional classification. ***One-Dimensional Warranty*** is the most common warranty type, which is based on product age or usage, but not both at the same time. Two-dimensional warranties are more complex and both age and usage time is considered. In automobile industry the two-dimensional warranties are often used. (Pham 2011, 103). In this master's thesis we focused only on one-dimensional warranties, because of the Case Company uses one-dimensional warranty policy.

Warranty types can be commonly grouped into *renewing* and *non-renewing warranties*. Non-renewing warranties can be divided into non-renewing free replacement warranty and non-renewing pro-rata warranty. Also renewing warranty can be either free replacement warranty or renewing pro-rata warranty. Difference between renewing and non-renewing warranties is that if product fails and company replaces or repairs the product or a part of product, on renewing warranty case the failed item gets a new warranty, whose terms are identical compared to original warranty. If a product with non-renewing warranty fails, a company will replace or repair the product or a failed part of product, but warranty period does not start again. The warranty expires at time W after purchase. (Blischke et al. 2011, 23-25; Chukova & Hayakawa 2004, 59-60)

Free replacement warranty is the most used for consumer goods. Manufacturer replaces, repairs or reimburses the failed product for customer during warranty period. It is suitable from a non-repairable inexpensive product (film) to an expensive repairable product (automobile). *Pro-Rata Warranty* means that if a product fails before warranty time has ended, manufacturer agrees to repair the failed product or refund the sale price of a product. This is commonly used for batteries. (Blischke et al. 1994, 47-50; Murthy 2006, 135-136) Other warranty types are group warranties, reliability improvement warranties, extended warranties (also called service contract) and second-hand warranties. (Blischke et al. 2011, 26-29)

3.3 Definition of warranty management

Warranty costs are unpredictable future costs and managing these costs is important to company. It is important to manage these costs and many warranty strategies are based on minimizing costs. Greater sales and revenue will be obtained if warranty terms are attractive and generous to the customer. Warranty servicing costs will naturally increase. If improving reliability and quality control, warranty servicing costs can reduce. The stated business objectives should be achieved by the strategic warranty management. This goal can be reached when all the different strategies are effectively integrated from an overall business viewpoint. (Murthy 2006, 65) Warranty management deals with all aspects of warranty and it is important issue for a company. Warranty management must be done in framework that integrates the technology and commercial issues by a manufacturer's point of view. It also should be done strategically over the product life cycle. (Murthy et al. 2006, 145).

Strategic warranty management should link technical and commercial planning and the product development process. Defining the profitability of a product, commercial and technical issues should interact strongly. In the figure 8 can be seen the product life cycle in warranty perspective. Information gained from this post-launch stage can be very helpful for the production lines and for design and development procedures. (Diaz et al. 2012, 325-326) Product reliability links primarily to design and production choices, when planning the desired product performance. Commercial issues (marketing, post-sale support, accounting etc.) deal with pricing, promotion, warranty terms selection and warranty service. Technology strategies and commercial strategies should be developed at the same time and mandatory is that they link each other. In product pricing, prediction of warranty costs is an important aspect. (Murthy et al. 2006, 67)

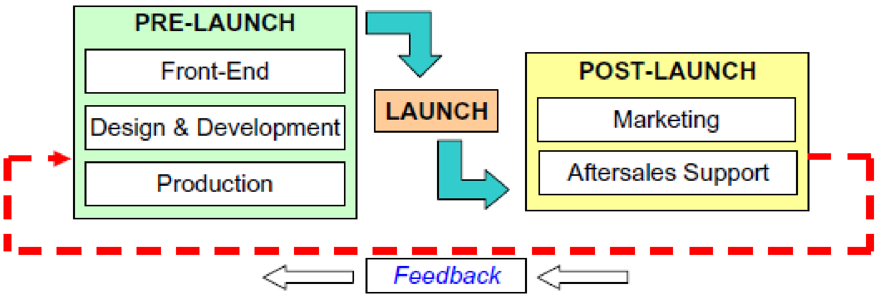

Figure 8. Product life cycle in warranty perspective (Diaz et al. 2012, 325)

Stages of management

For manufactures warranty management is important issue and three stages in the evolution of warranty management have been identified: (Blischke 2011, 31)

-Stage 1: Administration

-Stage 2: Operational improvement

-Stage 3: Strategic warranty management

At the stage 1 focus is the administrations of warranty claims and aim is to control warranty servicing costs. The focus of warranty management at second state is to understand the causes that lead to warranty claims and dissatisfaction of customer. At the stage 3, warranty has been observed from a strategic management perspective by the manufacturer. Product warranty management must be done in the overall product life cycle context. (Blischke 2011, 31-32)

3.4 Warranty cost analysis

The situation, where item has been returned under warranty, the manufacture is involved in various costs. These costs are unpredictable (consist of material, handling, labor, facilities). The following three costs are important to manufactures and also to consumers (Murthy et al. 2006, 139). Cost of warranty varies between 1-10 % calculated as a percentage of sale price. (Blischke et al. 2011, 29)

1. Warranty cost per unit sale
2. Life cycle cost per unit sale
3. Life cycle cost over repeat purchases

Warranty's basic cost is the sum of costs associated with servicing of a product that breaks down under warranty. These costs include the cost of replacement items, the cost of testing, repair personnel, facility, administrative costs and other cost elements. The warranty cost is a random sum of individual claim costs. Also the number of claims over warranty period is random. Warranty cost per unit sale can be calculated as the total cost of warranty divided by the number of units sold. (Rahman 2007, 48; Blischke 2011, 31)

Life cycle costs (LCC) is important to buyer and manufacturer, if the product is complex and expensive and it depends on the life cycle of the product. The first step in the life cycle is the launch of a product and the last step is the end of production of product. (Rahman 2007, 48)

Life cycle cost per unit sale. Some products are used for long periods, for example aircraft. One or more components will fail over the life of product and many replacement cases occur after the original warranty has expired and separate warranty will cover needed replacements. Purchases of a component should be repeated over the period L. A non-renewing warranty policy is a typical for repeat purchases for a component. The duration between repeat purchases is an uncertain. The cost over the life cycle is different for consumer and manufacturer. The cost for manufacturer includes the production cost and the cost servicing claims under warranty. The cost to the customer includes the purchase price and warranty cost and all claim cost after warranty period. (Murthy et al. 2006, 141)

Life cycle cost over repeat purchases. If warranty is renewing, the period is longer than in the case of one dimensional non-renewing warranty. Dynamically changes the expected number of claims per unit time and product reliability, usage intensity and other elements will affect this. (Murthy et al. 2006, 141-142)

3.5 Feedback-process

When the item failures, claim process starts. The most failures are objective, but some failures are subjective (depends on customer). The failure rate depends on field reliability and reliability depends on decision making during design and production of product. Feedback-process is described according to Blischke et al. (2011, 61-67). As can see in the figure 9, field reliability affects the product failure. The product failure, warranty terms and warranty execution influence on warranty claim rate. Warranty terms were introduced in section 3.2. Warranty execution means even though product has failure, customer does not use his/her right to the warranty, so all failures do not necessarily lead to a warranty claim. The following has been listed some reasons: customer has a strong dissatisfaction with the product, customer is not happy with the provided warranty services, exercising the claim is not worth, customer does not know about his/her right the warranty coverage or customer has forgotten it. Warranty claim leads to *servicing process*. It is complicated and includes many steps. The next description does not include all details, just major steps. First step is, when customer decides to make warranty claim. Customer contacts to warranty handling personnel, who collects the relevant data and information, related the failed item. The validation of claim will be estimate in the second step in the process by warranty handling person/manufacturer. Claim may be invalid, if warranty has expired or item has not failed. If claim is valid, in the third step, a failed unit will be repaired or unit will be brought to the manufacturer for repairing. If repairing is not possible, the customer will get a new product/unit and the failed one should be sent back to manufacturer. In the last step the manufacturer will examine and make more detailed analysis of the failed component; who is responsible for failed item, for example manufacture, vendor etcetera. Large amount of data and information should be generated. Sometimes the service agent will storage the warranty claims data or data need to be transferred to the systems of manufacturer.

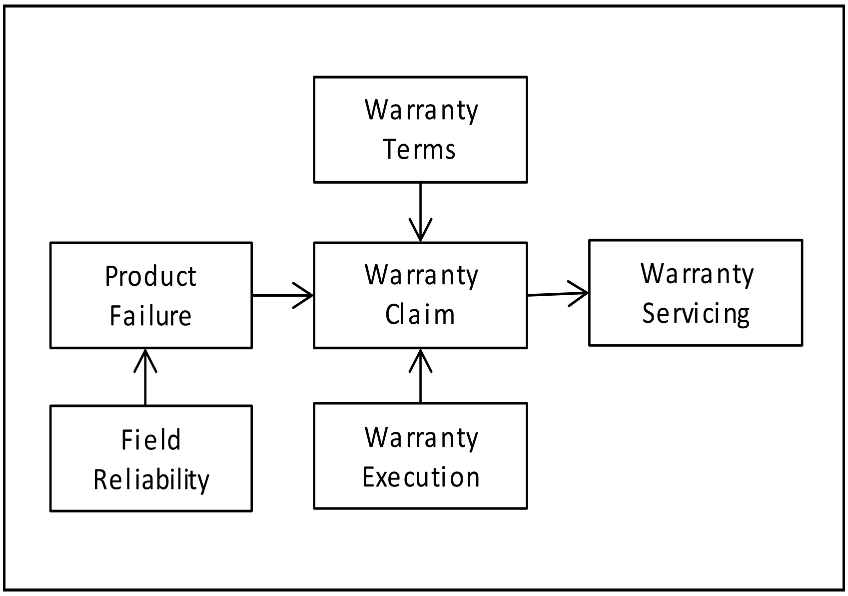

Figure 9. Warranty Process (Blischke 2011, 64)

Warranty data

Warranty data can be categorized in two groups which are: warranty claims data and supplementary warranty data. Claims data has been used to estimate future warranty costs. This approach is possible, when the product has been released into the marketplace and warranty claims are observed. When using claims data, there are many difficulties, for example variable delayed between failure time and, the time at which a claim is made, also statistical estimation can be problematic. (Murthy 2006, 142)

Typical record of warranty claims data consist of the following information: date of sale of the product, date of failure, date of claim made, model number of failed product, material cost, labor cost and handling costs. Claims data varies between companies, but usually it includes mentioned parts. (Manna et al. 2004, 105) Claims data are sometimes poor. This due the fact that data are provided by different sources for examples from consumers, dealers, repair personnel, and others over whom manufacturers has no control or only little. Claims data has some principle difficulties:

-Incomplete data; missing of incorrect entries
-Delays in reporting
-Lags in making claims
-Invalid claims
-Valid claims that are not made

Warranty data is usually quite messy and data quality may be a considerable problem. One of the most important objectives is estimation of claim rates and prediction of future claims. This is a difficult problem especially in the case of two-dimensional warranties.

3.6 Tools for warranty prediction

In this chapter will be briefly introduced the most used tools for predicting future feedback-levels. Generally, warranty claim prediction means trying to predict number of claims and warranty cost at the warranty coverage. For financial departments in company predicting warranty claims can be important for preparing their fiscal plans. The following techniques are the most used. (Wu 2012, 10-11; Wu & Akbarov 2011, 196-197)

-Lifetime distributions
-Stochastic processes
-Artificial neutral networks

-The Kalman filter and time series models

- Weighted support vector regression model

The idea behind *lifetime distribution* is to estimate a time-to-claim distribution and fit a lifetime probability distribution. Model tries to capture the dynamic characteristic features of failure rates in both early failure period and the natural failure period of the bathtub curve. (Wu & Akbarov 2011, 201; Blische et al. 2011, 312) The number of claims should be known also the number of products without claim. The most well-known lifetime distribution approaches are Weibull distribution and exponential distribution. Exponential distribution is a special case of Weibull distribution. (Wu 2012, 801) More information about Weibull-method is in the next chapter 4.

The Poisson processes, one- and two dimensional renewal processes, alternating renewal processes and Markov renewal processes are *stochastic processes*. All of the mentioned techniques can be used for forecasting. In stochastic processes each failure is counted even. In non-homogenous Poisson process (NHPP) the number of claims during warranty period is in the target. Some researcher reported in their studies that claim rate varies a lot between months. (Wortman & Elkins 2005, 224)

An artificial neutral network (ANN) is information processing paradigm and it has been developed to base on biological nervous systems, such as brains. (Khale & Nagendra 2007, 25-27) The idea of this paradigm is the structure of information processing system. The specific problem is solved by a large number of highly interconnected processing elements (neutrons) working in unison. Neutral networks are described as a black box, with inputs and outputs. For warranty analysis, inputs could be age or mileage and output could be the expected cost or number of failures. For example, if input is the age three months, output should be mean cumulative number of claims at age three months. The method is special, because it can “learn”. It means that a collection of known ages and number of failures is a “training set” and a new process will use this training set for prediction. (Rai & Singh 2005, 162-164) Neutral networks are well suited for forecasting and they have already been successfully applied in business world. (Sterqiou & Siganos 2014)

The Kalman filter was originally developed in control engineering and it is the optimal linear estimator. The Kalman filter plays a primary role in processing time series models. The Kalman filter is an optimal recursive data processing algorithm. It is more important to understand what the filter does instead of how it does it. (Harvey 1989, xi, 1-2) Kalman filter process all information that can be provided to it. (Maybeck 1979, 4)

Weighted support vector regression model was developed in the background of statistical learning theory. It is a nonparametric methodology for creating regression functions. That approach can be applied for two scenarios: when only claim rate data are available and when original claim data are available. That method was developed because other above mentioned approaches do not consider the fact that “warranty claims reported in the recent months might be more important in forecasting future warranty claims than those reported in the earlier months” and second fact is that other approaches were developed based on repair rates, which can cause information loss”. (Wu & Akbarov 2011, 196, 203)

According to Blische (et al. 2011, 312-315) different methods can be grouped parametric models or non-parametric models. Difference between these is that parametric models are based on statistical structure of data and that kind of data can be used for simulations. Non-parametric models do not make any assumptions about the underlying probability distributions of product lifetimes. Non-parametric models are suitable for cost prediction.

In the following table 1 were listed advantages and disadvantages of different forecasting methods and also different applications.

Table 1. Advantages and disadvantages, and possible applications of tools

	ADVANTAGES	DISADVANTAGES	APPLICATIONS	PARAMETRIC/NON-PARAMETRIC
LIFETIME DISTRIBUTIONS (Weibull, Exponential distributions)	-Extremely small samples are possible - a simple and useful graphical plot of the failure data -Best fit of life data -Many software available	-Complex → software is mandatory -The maximum likelihood estimators may not behave properly for all parameter values	-Reliability engineering and survival analysis -Survival analysis -Weather forecasting (wind speed) -Quality control -Warranty claims -Biomedical	Parametric
STOCHASTIC PROCESSES (Non-Homogenous Poisson Process)	- Useful for complex products -Useful for hybrid warranty (free replacement and pro-rata combination)	-Claim rate may vary over time	-Warranty prediction -Reliability engineering for example studying failure time	Parametric
ARTIFICIAL NEUTRAL NETWORKS	-Possible to use complex structure data -Special hardware devices designed	-This method is based on repair rates -Over fitting of data	-Sales forecasting -Industrial process control -Risk management -Medicine	Non-parametric
THE KALMAN FILTER	-Easy to implement and gives basic understanding -Incorporate all kind of information/data	Computationally complex method	-Hydro science -Weather and oceanography	Parametric
WEIGHTED SUPPORT VECTOR REGRESSION MODEL	-Usage possible even when only claim rate data +original data available -base on warranty claims reported recently	-Calculating is difficult	Developed for warranty claim forecasting	Non-parametric

3.7 Uncertainty in Forecasting

Two terms forecasting and estimating can be often interchanged, but the meaning of these two terms is different. *Forecasting* is used to for example for budget needs. The aim of forecasting is not provide absolute cost, but forecasting gives guidelines for business planning and budgeting. Forecasting method will influence to the result, if method is not accuracy or data is inaccurate, then uncertainty and risks are present. Method can be varied between intuitive forecasting and systematic, complex method, which is made using exact forecasting software. *Estimating* calculates a view of costs today and accuracy often varies within 5 % of actual costs. Estimating is conducted “bottom up” and manufacturing process details and good design are required for an accurate outcome. (Forecasting Guidebook 2014)

All main sources of uncertainty should be taken account to construct *a forecasting model for claims* and the best compromise between realism and simplicity must be sought:

-Process uncertainty
-Parameter estimation uncertainty
-Trends and cycles in claim frequency
-Short-term random fluctuations in claim frequency
-Heterogeneous data
-Uncertainty of future
(Wright 2007, 16)

4 The Weibull method

4.1 Background of reliability engineering

Definition of reliability is “the ability of an entity to perform a required function under given conditions for a given period of time”, Reliability can be measured by the probability that system will work without error a given time period under given operating conditions. (Teiweira & Soares 2012, 92)

Following the definition of reliability engineering by Kececioqlu (1991, 27): “Reliability engineering provides the theoretical and practical tools whereby the probability and capability of parts, components, products, and systems to perform their required functions in specified environments for the desired period of operation without failure can be specified, designed-in, predicted, tested and demonstrated, and the results feedback to engineering, manufacturing, quality control, inspection, testing, packaging, shipping, purchasing, receiving, sales, and service for improvements and necessary corrective actions”.

The key reasons for reliability engineering are: For a company to succeed in highly competitive and technologically complex environment, It is the most important to know the reliability of a product and to able to control it in order to produce products at an optimum reliability level. It minimizes the manufacturer’s cost and further it affects decisively to life-cycle cost. For every product there is a certain reliability, which the total cost of the product to the manufacturer is minimum. This is the optimum reliability level for the producer. It is not sufficient that product works shorter than its mission duration and it’s no need to design a product to operate much past its prospective life. Product failures have varying effect, ranking from little nuisances to catastrophe failures for example aircraft accident, so safety issues are also the most important target of studying in the field of reliability engineering. Reliability engineering covers reliability, maintainability and availability. These three areas are numerically quantified with the use of reliability engineering principles and life data analysis. (Reliasoft 2005, 7)

Product reliability affects to product failures, and reliability is influenced by several factors: under the control of the manufacturer for example material decisions/component reliability during the design and others under the control of the customer for example usage mode, environment and intensity. (Blischke & Murthy 2000, 35) *Product reliability* is one of the qualities of the product. Elements of quantified and measured reliability are:

1. Profitability
2. Performance
3. Time
4. Conditions

(Feigenbaum 1991, 574)

Reliability and quality:

The relationship between reliability and quality is very old. They go hand-in–hand and are complementary of each other. There is no reliability, without quality. A product, which has a higher reliability, quality must be good as well. Reliability is associated with design/material, whereas quality is associated with manufacture. Reliability of a product is its ability to maintain its quality under specified conditions for a specified time period. Important difference between quality and reliability is that one can build a reliable system using less reliable components but it's impossible to construct a poor quality system from poor quality components. The key reason is that reliability can be improved using redundant components, but quality of the product cannot be improved after it has been manufactured. It is only possible through modification of the product. (Mishra & Sandilya 2009, 6-7)

In the figure 10 shows a framework of product reliability. Framework incorporates many issues, which relates to each other. These issues are: technical, operational, commercial and management issues. Technical issues include: Understanding of deterioration and failure (material science), effect of design on product reliability (reliability engineering) and estimation and prediction of reliability (statistical data analysis). Operational issues include: Operational strategies for unreliable systems (operations research) and effective maintenance (maintenance management). Commercial issues includes: Cost and pricing issues (reliability economics) and marketing implications (warranties, service contracts). And Management issues include: Administration of reliability programs (engineering management), impact of reliability decisions on business (business management) and risk to individuals and society resulting from product unreliability (risk theory). (Blischke & Murthy 2000, 24-25)

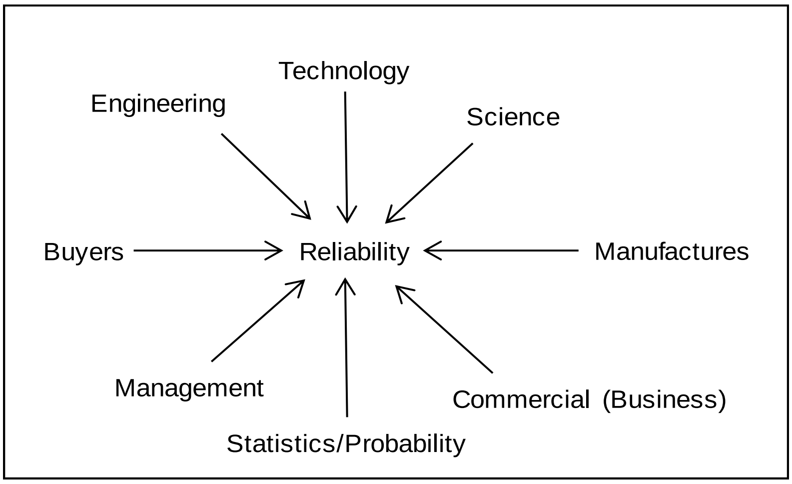

Figure 10. The framework for the study of reliability (Blischke & Murthy 2000, 25)

Bathtub curve is a much used engineering tool. The bathtub shape is characteristic of the failure rate of complex product or component and even the human body. The curve typically maps the failure rate versus time. In many cases, plotting the failure rate against a continuous time scale, the result will be bathtub curve. The reliability bathtub curve can be seen to divide into three periods. A failure rate seems to be the highest during the early life and the wear out. That's why the shape of curve is like a bathtub. (Roesch 2012, 2864) It is good to notice that curve will be different for two different conditions: is the component repairable or non-repairable nature. The constant failure rate is for non-repairable items, whereas, repairable item the failure rate can vary with time. (Mishra & Sandilya 2009, 58)

A graphical representation called the bathtub curve describes the lifetime of population of product as in the figure 11. The curve consists of three periods in the life of equipment: early, useful and wear-out life. Useful life period is a period when failure rate is constant and minimum. This period is the best in the life of equipment, because can be expected the lowest failure rate and the highest reliability and the least number of failures during this period. (Kececioqlu 1991, 79)

During the early life period, will occur early and chance failures and also during the wear-out life period usually chance and wear-out failures will occur. The reliability bathtub curve may not always look like an ideal curve as in the figure 11, but most cases products failure rate acts like the bathtub curve. (Kececioqlu 1991, 81)

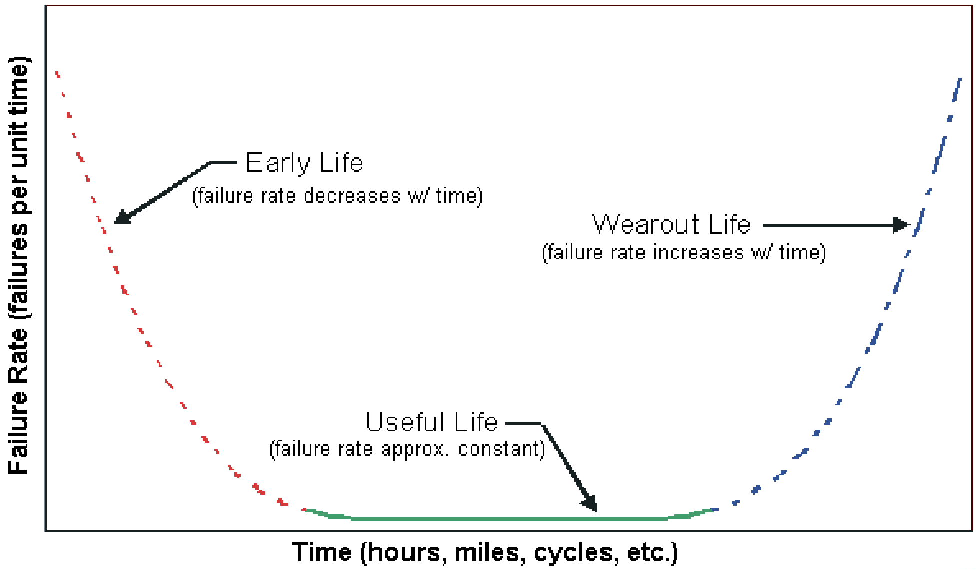

Figure 11. Bathtub Curve (Reliasoft 2014)

4.2 The Weibull distribution

The Weibull distribution has been proposed in 1937 by Waloddi Weibull, Swedish scientist. The Weibull analysis will be emphasized particularly for failure analysis. The Weibull distribution has many applications for examples in medical field, for life cycle costing, researching materials properties, warranty analysis and weather forecasting. The Weibull distribution is a well-known distribution in modern statistics. Weibull is continuous random variable and it can get any value along the positive real line (0, ∞) (Abernethy 2005, 1-5)

A general purpose of the Weibull reliability distribution is used to model material strength, times-to-failure of electronic, equipment or system. *The three-parameter Weibull probability density function, pdf*, is the most general distribution and it is defined by:

$$f(t) = \frac{\beta}{\eta}\left(\frac{v-\beta}{\eta}\right)^{\beta-1} e^{-\left(\frac{v-\beta}{\eta}\right)^{\beta}} \tag{1}$$

with parameters *β*=shape parameter, if *β*=1 the two-parameter Weibull distribution specializes to the exponential distribution, *η*=scale parameter, also is known as the characteristic value or in life testing applications as the characteristic life and γ=location parameter, also known as the threshold parameter, in life testing applications as the guarantee time, since failure cannot occur until x exceeds *β*.
(McCool 2012, 73)

In the case of *two-parameter Weibull*, location parameter γ is assumed to be zero:

$$f(t) = \frac{\beta}{\eta}\left(\frac{v}{\eta}\right)^{\beta-1} e^{-\left(\frac{v}{\eta}\right)^{\beta}} \tag{2}$$

If the location parameter *γ* is zero and the shape parameter is a known constant or *β*=constant =C, distribution is called the *one-parameter Weibull*:

$$f(t) = \frac{C}{\eta}\left(\frac{v}{\eta}\right)^{C-1} e^{-\left(\frac{v}{\eta}\right)^{C}} \tag{3}$$

Other commonly used distribution is *The Mixed Weibull Distribution* and it will be introduced next. The Distribution is used for modelling the behavior of components, systems exhibiting multiple failure modes so called mixed populations. It is mixing different Weibull distributions for different stages of the product's life so it gives the global picture of the life of a product.

$$Fs(t) = \sum_{i=1}^{S} p_i \ \frac{\beta}{\eta}\left(\frac{v}{\eta}\right)^{\beta-1 e^{-\left(\frac{v}{\eta}\right)^{\beta}}} \qquad (4)$$

,where the number of subpopulations is equal to the value of S. That results in a total of (3 ·S-1) parameters. In other words, each population has a p_i portion or mixing weight for the i^{th} population, shape parameter β_i for the i^{th} population and scale parameter η_i for the i^{th} population. Parameters are reduced (3 ·S-1) and that's why following condition can be used:

$$\sum_{i=1}^{S} p_i = 1 \qquad (5)$$

(Reliasoft 2005, 30, 33-34)

Sometimes any distribution in Weibull-distribution family does not fit probably for modeling the set of data. In that case, good distribution is *the generalized gamma distribution, G-Gamma distribution*. This distribution behaves as other distributions based on values of the parameters.

The generalized gamma function is not often used to model life data by itself, but its ability to behave like other commonly-used life distributions. Distribution is identical to the Weibull distribution, if λ=1 and, if both λ=1 and σ=1, the distribution is identical to the exponential distribution, and as mentioned earlier, exponential distribution is special case of the Weibull distribution, where β=1. (Reliasoft 2005, 34)

4.3 The Weibull statistical properties and characteristics

The three-parameter Weibull cumulative density function, cdf is given by:

$$F(T) = 1 - e^{-(\frac{T-\gamma}{\eta})^{\beta}} \tag{6}$$

The Weibull Reliability function can be derived using cumulative distribution function, so it is:

$$R(T) = e^{-(\frac{T-\gamma}{\eta})^{\beta}} \tag{7}$$

Reliability function represents the probability of success of a unit in undertaking a mission of a prescribed duration.

The Conditional reliability function is

$$R(t|T) = \frac{R(T+t)}{R(t)} = \frac{e^{-(\frac{T+t-\gamma}{\eta})^{\beta}}}{e^{-(\frac{T-\gamma}{\eta})^{\beta}}} \tag{8}$$

,where *t* means the duration of the new mission and *T* means the duration of the successfully completed previous mission.

The failure rate function ë(T) is given by:

$$\text{ë}(T) = \frac{f(T)}{R(t)} = \frac{\beta}{\text{ç}}(\frac{T-\beta}{\text{ç}})^{\beta-1} \tag{9}$$

Characteristics of the Weibull distribution

As mentioned previously, shape parameter β is known as a slope. The value of β is equal with a slope of the regressed line in a probability plot. Marked effects on the behaviors of distribution can be noticed by different values of shape parameter. The parameter β is dimensionless. (Reliasoft 2005, 113-120)

First will discussed about the effect of beta on the pdf. Shape of probability density function gets variety of form depends on value of beta. In appendix 1 there is the figure about behavior of beta on the pdf. For 0 <β≤ 1, f(t) decreases monotonically and is convex as T increases beyond the value of γ. If value of β is bigger than 1 f(T) is zero and T is also zero. F(t) increases as T → $\bar{T}$ and decreases thereafter. If β < 2.6 the pdf is positively skewed and for β >3.7 the pdf is negatively skewed. The value of β effects on the Weibull failure rate function. In the appendix 2 have been pictured effects of different values of β. A marked effect on failure rate has the value of β. The population's failure can be deduced by value of β. Populations with β <1 show a failure rate that decreases with time. Populations with β=1 have a constant failure rate and populations with β>1 have a failure rate that increases with time. The Weibull distribution and varying values of β form all three life stages of the bathtub curve. (Reliasoft 2005, 113-120)

The scale parameter η effects on the distribution as following way. While β and γ are constant and increased, the value of η the distribution gets stretched out to the right and its height decreases. If η is decreased, the distribution gets pushed in towards the left and its height increases. The table is shown in Appendix 3. (Reliasoft 2005, 113-120)

4.4 Parameter estimation and data classification

Each method has advantages and disadvantages for estimating the parameters of the Weibull distribution. In the method of estimation it is relevant to consider the following characteristics according to McCool (2012, 132):

1. Applicability to censored samples
2. Precision. This refers to the scatter in the sampling distribution of the estimate: the less scatter, the greater precision.
3. Applicability to interval estimation
4. Degree of bias. An estimator is a biased estimator if the average value of the estimate over repeated samples is not equal to the true value of the quantity being estimated.
5. Simplicity of calculation.

When a suitable distribution has been selected, the parameters of the distribution need to be estimated. Several parameter estimation methods are available, but in this thesis will be introduced briefly one method: *maximum likelihood method,* which is the most relevant for this master's thesis. The basic idea behind method of maximum likelihood estimation (MLE) is to obtain the most likely values of the parameters, for a given distribution, that will best describe the data. (Reliasoft 2005, 49)

The method of Maximum likelihood is the most varied method for fitting models to data and used for constructing estimators. The purpose is to use a parametric statistical model to describe a set of data that generated a set of data. A many of statistical models and much kind of data, for examples continuous, discrete, censored, truncated can be estimated by maximum likelihood method. The method is simple to apply and estimators are optimal in large samples. (Cook et al. 2003)

The Maximum likelihood Estimation method has the properties of unbiasedness and minimum variance in large samples. The method brings estimates of the distribution parameters that make the probability of appearance of the observed sample the largest. "When the sample is right censored and the number of failures is designated *r* and the number of censored observations is n-r, it is convenient to renumber the observations so that the first r, x_1, x_2,… , x_r, represent the failure times and the remaining x_{r+1}, x_{r+2}, … ,x_n are the times at censoring." With this notational convention, the likelihood function can be written as: (McCool 2012, 146)

$$L = C \prod_{i=1}^{r} f(x) \cdot \prod_{i=r+1}^{n} [1 - F(x_i)] \tag{13}$$

“The constant C varies with the type of censoring but is independent of the parameters of the distribution and not relevant to finding the maximizing values of the parameters. A failure contributes a term f(x) evaluated at the censoring time. It is generally convenient to deal with the logarithm of L rather than L directly. The parameter values that maximize ln L also maximize L. Designating the natural logarithm of L by l.” Formula can be written as: (McCool 2012, 146)

$$\ln L = l = lnC + \sum_{i=1}^{r} \ln[f(x_i)] + \sum_{i=r+1}^{n} \ln[1 - F(x_i)] \tag{14}$$

Data classification

When the life data are analyzed, all of the units in the sample have not failed. This kind of data is so called censored data. Three types of censoring schemes are possible, but the following is introduced only right censored, as known suspended data, because that kind of data is used in simulations. Data is right censored, if it is known the exact value of random variable is greater than a bounding value. For example, if five units have been tested and three have failed by the end of test, there will be suspended data for the two unfailed units. Event of interest is to the right of our data point, that’s why name, right censored data. (Reliasoft 2005, 59; (McCool, 2011, 131)

Previous research about the Weibull analysis

Although the Weibull distribution has been used for many applications for example failure analysis and warranty forecasting still many studies has not been made related to the warranty forecasting. Many studies have not been made in companies or in the practical point of view. Practical studies would be interesting, if consider this master's thesis. Still, Summit (2012, 451-464) has researched how the Weibull model was used to simulate the occurrence of warranty claims. Australian car manufacturer's warranty data has been used and the reliability of the component has been estimated. The required time length for getting accurate results was researched. The study has been made for a single component, but also a simple product or a subsystem can be suitable. The study of Summit shows that at least two years of a data are required to obtain acceptable estimates of the Weibull parameters. The Weibull model provided a good fit to the warranty data, when the time interval was two years and when the Weibull parameters were based in the simulations. The one-year data was insufficient. Why the one-year data gave unsatisfactory estimates? Summit observed that only 26 claims were received in the first year, 199 during second year and 279 claims in the third year and 27 after three years. The total number of claims was 531 pieces. Only 5 % of claims were received in the first year. If only one year data will be examined, it doesn't consider that actually small amount of claims comes in the first year and large amount of feedbacks were received in the third year. "As time increases to two or more years, the number of claims increases, enabling a better fit to the more numerous data points."

5 The Case Company

5.1 The Company presentation

The Case Company of this master's thesis operates in the project business. The Company is one of the leading companies in its field. It acts globally and has units and the manufactures all over the world. One of the high priority areas of the company is quality. The Company offers the high quality products and services, so quality is one of the competitive advantages of company. Chapter 2 is about managed quality costing and the cost of poor quality. As stated warranty cost is a part of the external error cost group. External error costs are visible to the customer and affect the image of products and the Company. If the product does not meet the customer's expectations, the customer will not buy products again, which will affect the future the indirect poor quality costs and the image of the company.

The warranty management is an important field for the Case Company, because the level of quality and the reliability directly affect the warranty costs. Furthermore, in the field, where the Case Company acts, safety issues are important and stated by law, so reliability and safety issues are mandatory to manage correctly. An important task is to forecast warranty costs correctly, because budgeting is based on the forecasted costs and provisions will be posted according to the forecasted provision. Generally speaking, quality costs can be budgeted and because of that, the Company is forced to determine the clear targets. Quality cost can't only be the registration of deviation. Information should be used for active planning. Even if, the target of this master's thesis is to examine the forecasting process, not improve the quality of the product, the link between the quality of the product and the warranty costs is important to understand. If costs can be forecasted correctly, the quality of the internal process will increase. If the cost of poor quality increases, it means that the quality-level has decreased.

The Company manufactures the complex products, which consists of different components. The components are produced in the different factories. The factory in *Finland* is the pilot one and all findings will be tested in other supply units. The other supply units are located in South Europe and America. All supply units manufacture the similar products, but their production levels differ. Even though all supply units manufacture similar products, the complexity of the products varies. This means that the products are more complex, like the so called C-process products, which are produced in the factory in Finland. Whereas, products manufactured in South-Europe and America, are more standard products, so called A-process products. The supply units can be divided into the component factors (called profit centers). One product consists of the different components produced in the different component factories. Even if, the complexities of the products vary, all products are handled in the same way in the Weibull analysis. The complexity of the products does not affect the procedure of the analysis, even if the complexity can affect the result of the analysis: How suitable is the analysis for the complex product versus the less complex products?

The different factories and the profit centers have been named the following way:
In *Finland factory* there are 5 different profit centers: FK1, FK2, FK3, FK4 and FK5. FK1 is the supply unit, which delivers the whole product. The others FK2, FK3, FK4 and FK5 are component factories and they deliver components to FK1 and to other supply units.

In the *South Europe factory,* there are 4 different profit centers: IK6, IK7, IK8 and IK9. Exactly like above, IK6 is the supply unit, which delivers the whole product. The others IK7, IK8 and IK9 are component factors.

In the *America factory,* there are also 4 profit centers: AK10, AK11, AK12 and AK13. AK10 is the supply unit and the others are component factors.

The last one is TK15. It is also a supply line, but it delivers products to different kinds of customers than the other supply units. The component factors in Finland and the IK9 factor in South Europe deliver components for shipments for TK15.

The Case Company has three different warranty types, but this work will be focused only on the provision of *general warranties*. The general warranty provision covers the expenses related to the warranty claims of completed goods sold with a valid warranty during the accounting period or earlier. The warranty period is 42 months after the complete goods are sold for all products or 12 months from hand over to the customer. The warranty type is a one-dimensional (time) non-renewing free replacement warranty.

5.2 Problem description and objectives

In this master's thesis, problems related to predicting a warranty provisions will be solved. The Company has noticed that the amount of forecasted warranty provision is much smaller than the actual warranty provision. The Company wants to know if the Weibull method is the correct one for forecasting provisions. If the Weibull is not suitable for the Case Company, it is possible that the Company will abandon the method.

One part of this work is to establish a harmonized control model in the different sites of the company. It means that there will be a control model created, where actual costs are compared to forecasted costs. Every profit center calculates their warranty provisions but this is it. They don't have any procedure or the system for a systematic "follow-up" of forecasted costs versus actual, realized costs. In this thesis a suggestion will be developed, on how the Case Company can compare actual and forecasted costs.

The profit centers take their data from a database called Qlikview. One objective is to document the Qlikview parameters of the profit centers. Parameters determine what kind of data Qlikview gives for users, so this is a critical phase in the forecasting process, because the Weibull simulations are made based on the Qlikview data. More about Qlikview and the parameters will be mentioned in the next chapter.

The main Objective of this master's thesis is to examine, if the Weibull analysis is a suitable method for forecasting the warranty costs in the Case Company. **The first sub objective** is to research and document, which parameters will give the best result in the simulations.

The second sub objective is to establish a harmonized control model for following actual costs and forecasted provision costs. This will be conducted by doing an Excel-model. **The third sub objective** is to document the Qlikview parameters of each profit center.

5.3 Process description

Feedback-process

It is important to understand the processes related to warranty forecasting. Next up will be the introduction of the steps of the feedback-process according to the process flow diagram (shown in appendix 4). In the Y-axis, there are four parts, front line, feedback-team, factory and invoice handler. In step A1, the front line notices or gets information about a problem, failure, etcetera of the product, and then the front line opens a Feedback-notification. In the step A2, the front line determines defective types and who is responsible for the problem. The supply line, SL or front line, FL are two options In step A3, if the failure is not caused by the supply line, Front line cause code, FL-cause code will be determined. In step A4, if the failure is caused by the supply line, then a Supply-line cause code, SL-cause code will be determined. In step A5, the front line sends a feedback-notification to the Feedback-team. In step A6, the Feedback-team opens the Feedback-sales order in SAP according to the Feedback-notification. In step A7, the Feedback-team examines more specifically, who responsible for the failure and determines the needed replacements material. In step A8, if the factory is responsible for the failure, the feedback-team sends an order to the right factory. In step A10, the factory receives a FB-order and in step A11 the factory supplies right material. The factory receives an invoice in step A12 and in step A13, the factory posts the costs of the material, freight and engineering to SAP. In step 9, in case, a factory is not in responsible for the failure, the Feedback-team orders the right material from an external supplier or another place. In step A14, an invoice handler will post a material, freight, a handling and engineering costs to SAP. The last step A15, an invoice handler pays the invoice.

If the feedback-process works correctly, it can be assumed that all costs in SAP are correct and the costs can be trusted in the forecasting process In the Case Company, the process works correctly so in this master's thesis, it is assumed that the used data is reliable and usable. For the forecasting process, data is taken from Qlikview. The data goes automatically from SAP to Qlikview.

Qlikview-parameters

Qlikview is business intelligence, BI system, for reporting and analysis. Qlikview uses databases, which the company already has. It provides a one-click access to dashboards and anyone can build and modify an analysis quickly. (Qlikview 2014)

Data for the forecasting analysis will be taken from Qlikview. If a right data can be received, the parameters should be selected correctly in Qlikview. For the forecasting analysis, the next parameters should be determined as in the figure 12, but the next introduced are Category, Cause code, Defect type group and FB responsibility.

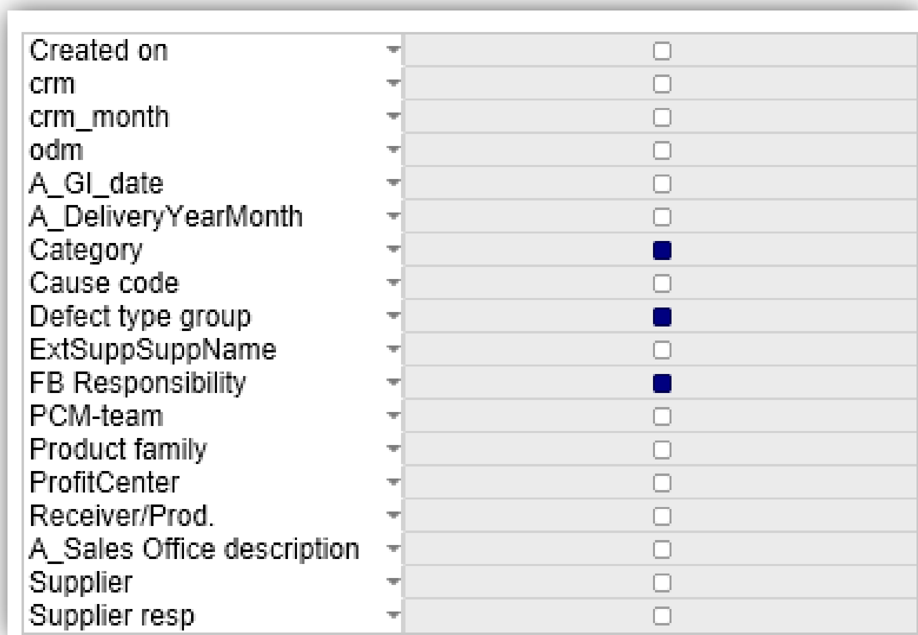

Figure 12. The selection of Qlikview-parameters

Feedback categories in the Case Company are: first category: Material Request supply line (SL) responsibility. The second category is Category 2: Material Request front line (FL) responsibility. And the third one is Category 3: Improvement Proposal (No material request). The first one is the most relevant for this master's thesis, so next up will be a more specific introduction of category one. The responsibility of Category 1 is the supply line, which means that the supply line should pay all costs of the feedback (material, freight, and engineering). When the supply line gets the feedback with Category 1, it should check if the warranty is still valid or if the warranty period has not ended. Category 2 means that the front line should pay all costs of feedback.

Cause code tells who is responsible for a failure, a problem or a material missing. The cause codes are presented the profit center by the profit center in the next chapter.

Different defective types are *material damaged*, *material defective*, *material missing* and *material wrong*. The descriptions of the defective types are in the figure 13.

CODE	REQUIRED INFORMATION
Damaged	In cases of damage caused by transportation company. Following requirements are needed: The visual damage must be identified on transportation documents. Damaged packages or components should be photographed and include in the feedback. If material damaged is found inside the package, the FL should describe what damage has occurred (before or after installation) and whose is responsible for damage.
Defective	State what happened before the defect occurred with any error messages codes.
Missing	Original order and delivered material/component should be compared to each other. Packing list and CMR documents should be checked and copies of these documents should be submitted with the feedback.
Wrong	Check what was received and what should have been delivered (material number/description). If SL has been sent wrong material, new material should be sent by SL and SL should pay it.

Figure 13. The Defective types

A feedback-responsibility should also be determined. Three options are available: Supply line responsibility, Front line responsibility and undefined. All factories and the profit centers use *Supply line responsibility*.

6 The simulations of different factories

6.1 The Presentation of the software and the simulation

The software the company uses for forecasting is called Weibull++ by Reliasoft. The software can be used for reliability and a life data analysis. Six different analyses are possible with the use of Weibull++.

Degradation analysis: User can extrapolate failure times from performance data.
Warranty analysis: which provides methods for extracting life data from sales and returns information and it enables user to forecast future returns.
Test design: User can plan test strategies for few or no failures.
Nonparametric Life Data Analysis: User can analyze a life data without assuming an underlying distribution.
Competing failure modes (CFM): is a method for analyzing multiple failure modes simultaneously
Test of Comparison: This provides a basis for comparing data sets.
Stress-Strenght: Analysis allows the determination of the probability of stress exceeding strength.
Risk analysis and probabilistic Design with Monte Carlo simulation: User can perform a simple relationship-based analysis. Many applications are available based on this type of the simulation, for examples: Probabilistic design, risk analysis, quality control etc. (Reliasoft 2005, 421-422)

Next a more specific way will be introduced, on how *warranty analysis* is made. The warranty analysis will be introduced through an example made by Reliasoft (2005, 427-442). The analysis will be done in exactly the same way in the Case Company as in the example. The numerical example was used for getting a better understanding of the analysis, because exact costs and numbers of the Case Company have not been shown in this master’s thesis.

Weibull++ provides three different data entry formats for warranty data. The Case Company uses the *Nevada Chart Format*. The delivery and return (claim) can be arranged in a diagonal chart as in the table 2. A delivery Year/Month means the month, when the product has been delivered. Return means how many products have been returned in a month. For examples products sold in June in 2009 has gotten 5 claims in July 2009. The products sold in June have gotten 0 claims in August 2009.

Table 2. Nevada Chart Format

	Returns by Month							
DeliveryYear/Month	200907	200908	200909	200910	200911	200912	201001	201002
200906	5	0	4	5	2	2	4	0
200907	0	3	5	8	0	1	0	2
200908	0	0	4	1	5	0	1	5
200909	0	0	0	4	6	3	3	1
200910	0	0	0	0	9	5	1	0
200911	0	0	0	0	0	6	1	4
200912	0	0	0	0	0	0	6	2
201001	0	0	0	0	0	0	0	6
201002	0	0	0	0	0	0	0	0

Usage of the Nevada format allows converting shipping and the warranty return data into the standard reliability data form of the failures and the suspensions. For each time period, there will be a number of shipped products and shipped products will failure or not failure. “All of the units that were shipped and have not failed in the time since the shipment are considered to be suspensions. This process is repeated for each shipment and the results tabulated for each particular failure and the suspension time prior to the reliability analysis.” (Reliasoft 2005, 433)

In the table 3, there are shipments and returns in the monthly level. For example in June 2003 the company has had 100 shipments and in July the company has received 3 returns, in August 3 return, in September 5 returns and in other months shipments are the same.

Table 3. Shipments and warranty returns of the example company

			RETURNS	
	SHIP	Jul.2005	Aug.2013	Sep.2005
Jun.2013	100	3	3	5
Jul. 2013	140		2	4
Aug. 2013	150			4

The data should be examined month by month. 100 units were sold in June and 3 units were returned, so 3 failures in July for the June shipment and 3 failures in August and September. At the end of three months, there were 11 failure units of 11 units shipped in June, so 89 are still operating. For July shipment, 2 units were returned in August and 4 were also returned in September. So 140-2-4 =134 units are still operating after two months. In august 150 units were shipped and 4 failed in September, so 146 units are still working after one month. The following presents failures and suspensions of all four months in the table 4. (Reliasoft 2005, 434)

Table 4. Example of failures and suspensions of shipped and returned units.

Failures at 1 month	F1=3+2+4=9
Suspensions at 1 month	S1=146
Failures at 2 month	F2=3+4=7
Suspensions at 2 month	S2=134
Failures at 3 month	F3=5
Suspensions at 3 month	S3=89

Warranty prediction

When the data has been taken from the database (the Case Company uses Qlikview), then the user needs to use the Weibull++ software. First, a user has to select a time period. Sales data should be pasted to the Quantity-in-service window, as well as return data should be pasted there. Then the software analyzes, which distribution fits the best way according to the plots. The software will select the best fitting distribution, but the distribution selected by the software is not always the best, so the user should check that the plots settle in the curve. At the same time, when the best distribution has been selected, the software estimates the parameters: (in example parameters are β=2.49 and η=6.70) using maximum likelihood estimation introduced previously. In this case the Two-parameter Weibull Distribution has been used. So the shape parameter β and the scale parameter η have been used, but the location parameter γ not.

There are 89 units for the June shipment, which have successfully operated until the end of September, T=3 months. The probability of one of these units failing in the next month (t=1) is:

$$\mathrm{Q(t|T) = 1 - R(t|T) = 1 - \frac{R(T+t)}{R(T)}}$$

$$\mathrm{Q(1|3) = 1 - \frac{R(4)}{R(3)} = 1 - \frac{e^{-\left(\frac{4}{6.70}\right)^{2.49}}}{e^{-\left(\frac{3}{6.70}\right)^{2.49}}} = 1 - \frac{0.7582}{0.8735} = 0.132}$$

The probability of failures should be calculated next. The expected number of the failed units during the next month is:

$$F1 = 89 * 0.132 = 11.748 \approx 12\, units$$

The same calculations will be repeated for the July shipment. 134 units operating at the end of September, with an exposure time of two months. The probability of failure is:

$$Q(1|2) = 1 - \frac{R(3)}{R(2)} = 1 - \frac{0.8735}{0.9519} = 0.0824$$

The value will be multiplied with 134 units, so the number of failures is:

$$F2 = 134 * 0.0824 = 11.035 \approx 11\, units$$

Finally, for the august shipment 146 units operate at the end of September. The probability of the failure in the next month is:

$$Q(1|1) = 1 - \frac{R(2)}{R(1)} = 1 - \frac{0.9519}{0.9913} = 0.0397$$

The value is multiplied by 146 units and the number of failures will be calculated as:

$$F3 = 146 * 0.0397 = 5.796 \approx 6\,units$$

The total expected return from all shipments is the sum of all failures, *29 units*. This method is quite simple for different future sales periods. If the number of units that are expected to sell or ship in the future will be listed by an user, then these units are added to the number of units at risk. In the next step, the software automatically generates the forecast of the future returns. The amount of feedbacks has only been examined in this example. The cost of feedback is out of the example.

The last point of the forecast analysis is how to examine the Non-Homogeneous Data. In the previous example, it was expected that all shipments or actual products of all shipments were homogeneous. In many cases, as the product matures, design changes, modifications or improves the reliability, a failure of different products varies. If the population is a non-homogeneous, homogeneous products should be examined separately. A life model should be fitted for each homogeneous group, because the expected returns for each group differ from each other's. (Reliasoft 2005, 442) In the Case Company all products are handled as a homogeneous population, even if the products are different and the data consists of many products.

Selecting the best fitting distribution

As mentioned, the simulations have been made using the Weibull++ software. The software selects the best fitting distribution according to the data. A user should determine which distribution (the Weibull 2-distribution, the Weibull 3-distribution, the G-Gamma or the Mixed Weibull distribution) will fit the most accurate according to the plots. The software also calculates all parameters (for example in the case of the Weibull distribution: shape, scale and location parameters). Some examples of the good fitting distributes will be introduced next. The figure 14 is an example of a mixed Weibull distribution. This is the most suitable distribution for FK1. The Data has not been tested because of a reason, that the Weibull++ software tells which distribution is the best or which distribution can't be used at all. So this software is a very user friendly.

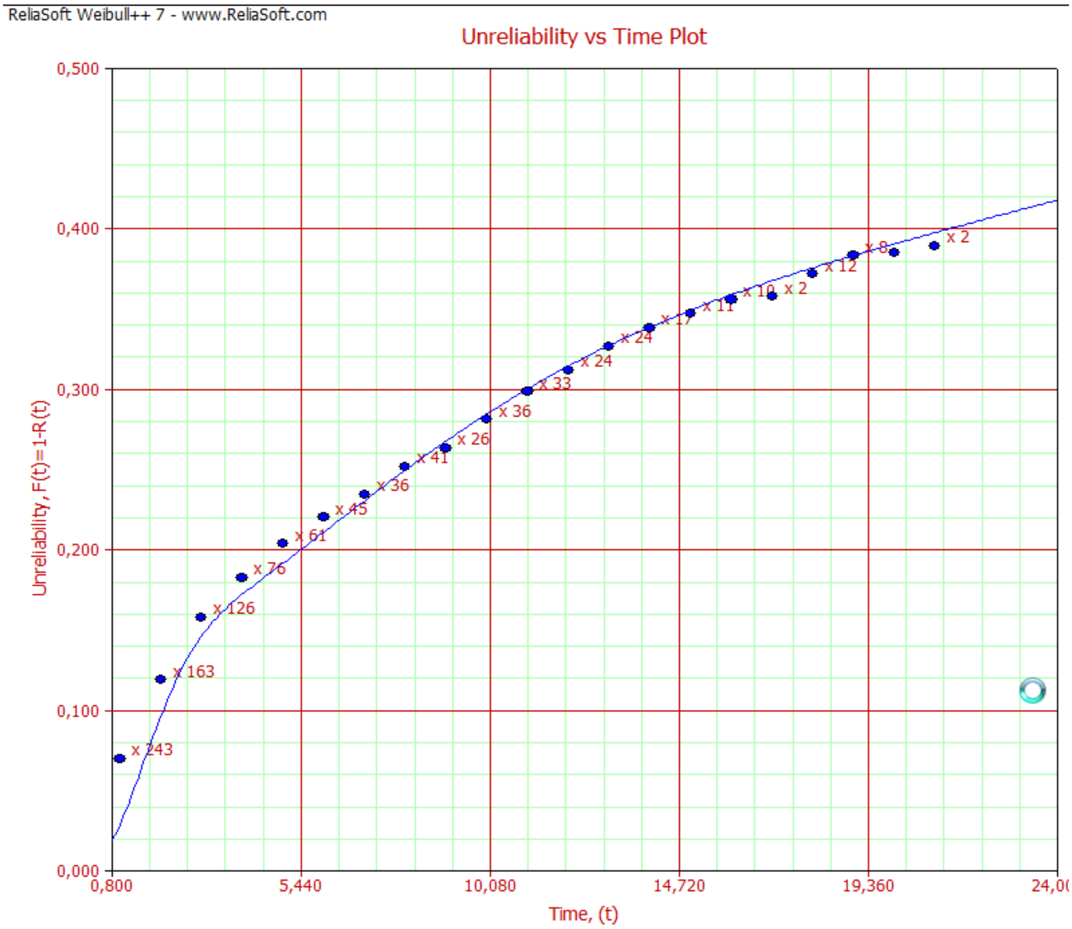

Figure 14. The Mixed Weibull distribution in FK1

The best suitable distribution for FK2 is in the next figure 15. This distribution is also a mixed Weibull distribution. As can be seen, the mixed-weibull distribution fits very well.

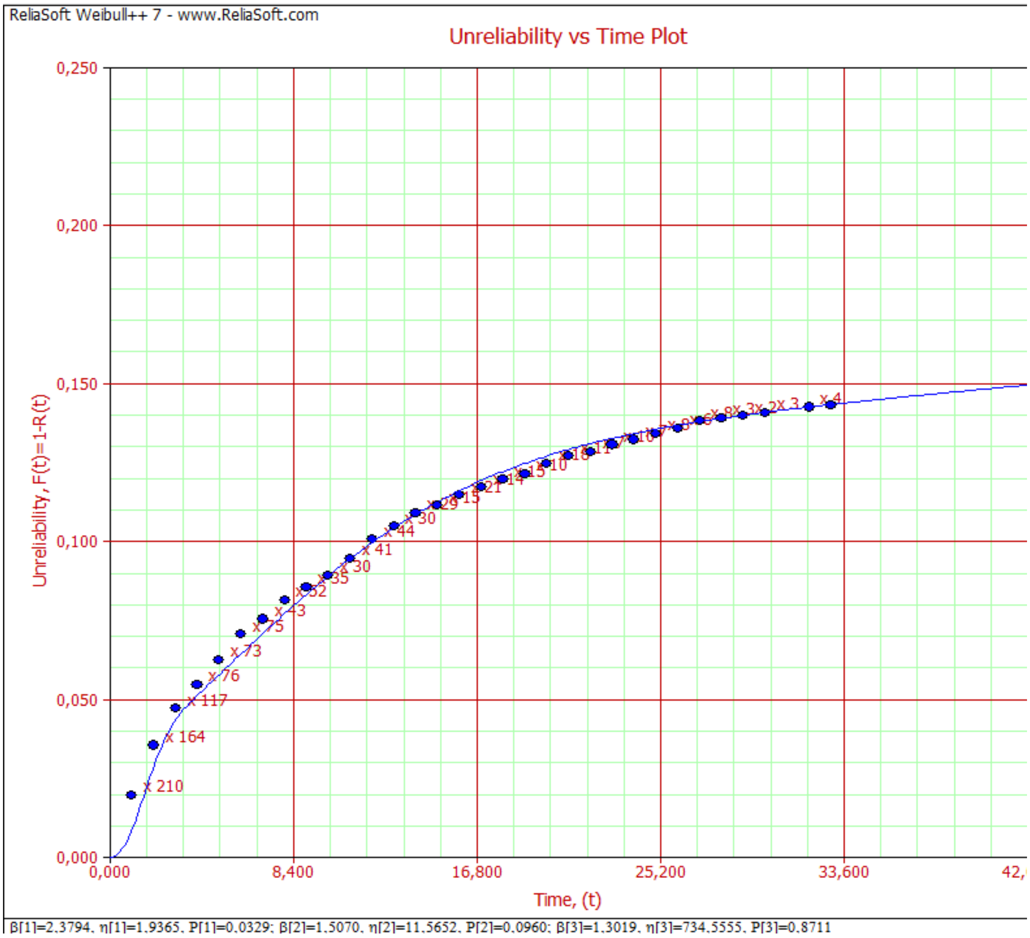

Figure 15. The Mixed Weibull distribution in the FK2

The Simulations in the Case Company

As mentioned in chapter 5.2, the company has factories in South-Europe, America and Finland. Every factory consists of the different profit centers. Warranty forecasting is handled separately in the every profit center, but they have the same method for predicting warranty costs. The principle is that in the every profit center the same delivery time period, which is 42 months back, should be used. The reason for using 42 months is that the warranty period of the Case Company is 42 months. Qlikview will provide all the previous deliveries, month by month, and the delivery time period is as earlier mentioned, 42 months. The Nevada Chart can be gotten from Qlikview, where all returns are organized diagonally. Nevertheless, some profit centers have noticed, that 42 months is a too long time period, so they have shifted to use 24 months or 18 months instead of 42 months. In this master's thesis both 42 months and 24 months will be tested. The average feedback cost is also available automatically in the Qlikview.

Future deliveries are also needed for the Weibull analysis. The time period for the future deliveries is 12 months. Some profit centers have used just an average of previous deliveries, but the official forecast, called DSB, is also available. In the simulations both have been tested: *future forecasted deliveries (DSB)* and *average of early deliveries*.

The cost of one feedback is the average cost of the previous 12 rolling months' feedbacks. The cost includes a material, freight and engineering costs for the feedback. Those kinds of feedbacks that do not have an invoice posted yet, should be excluded due to the reason that it would alter the average costs. Data for the feedback has to be taken from the database: Qlikview. The average cost of feedback is needed for calculations.

In the figure 16 has been shown a warranty forecasting process in the Case Company. Data are taken from Qlikview. Three kinds of data are needed for the Weibull analysis: ***Nevada chart format (feedback returns)***, ***number of previous deliveries***, and ***average feedback cost***. Future forecasted deliveries are needed, but the data will be taken from another place. The data will be pasted to the Weibull as described earlier in the chapter "warranty prediction". The Weibull estimates parameters and the software selects the best fitting distribution. When the best fitting distribution has been selected, the warranty data can be sent to Excel. In Excel the data should be edited to fit the right form.

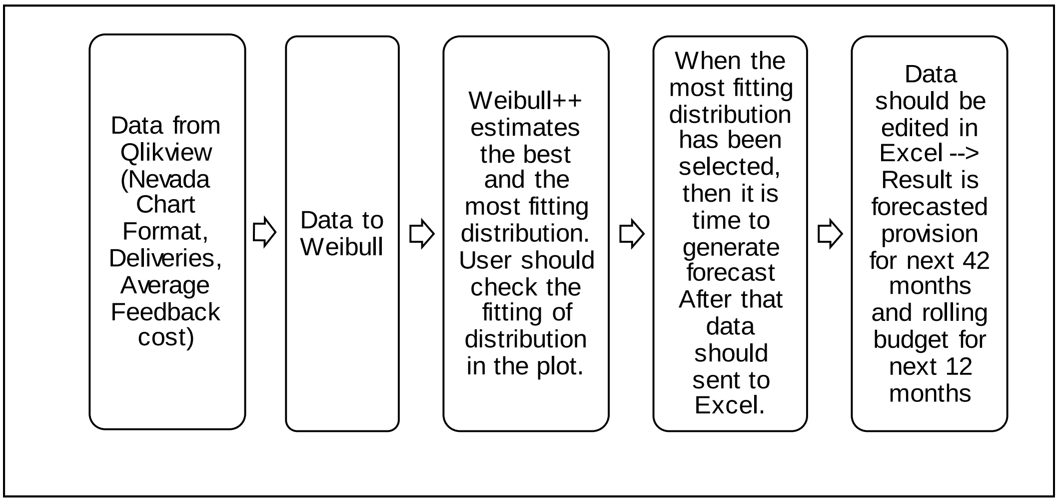

Figure 16. The Warranty forecasting process

Two different calculations will be made: a provision for next 42 months and the rolling plan or a budget for the next 12 months. In the figure 15 the form of forecasting in Excel can be seen. In the X-axis, there are future months with forecasted feedbacks. In the X-axis there are old delivery months. For example, the first cell (marked as red, 2012/05, Dec12) means that the shipment delivered in 2012/05 has gotten 4 feedbacks in December 2012.

The rolling plan includes future forecasted feedbacks of old deliveries, but also feedbacks of forecasted deliveries, even though the provision does not include the expected feedbacks of future deliveries. As can be seen in the figure 17, the provision is calculated by excluding the feedbacks of future deliveries from the "Rolling plan" (Rolling plan minus amount of feedbacks of future deliveries). So the amount of the feedbacks in the provision is smaller, because the number does not include the expected feedbacks for expected future deliveries, only feedbacks for deliveries, which have been already shipped.

A provision for the next 42 months should be calculated multiplying the forecasted future feedbacks with the average feedback costs. The other costs should be calculated using the forecasted data as well. The rolling budget for the next 4 quarterlies will be calculated almost the same way, except for the fact, the forecasted future feedbacks include also feedbacks, which can be expected to come.

This amount of the future feedbacks will be multiplied with the average feedback cost. Why does the Company calculate the provision and the rolling plan in this way? The rolling plan is for budgeting and planning purposes, but the amount of the provision is sent to bookkeeping, so a provision can't include "expectations" of forecasted future deliveries and feedbacks. The provision includes only expected warranty responsibilities of already delivered shipments.

	B	C	D	E	F	G	H	I	J	K	L	M
1		Dec 12	Jan 13	Feb 13	Mar 13	Apr 13	May 13	Jun 13	Jul 13	Aug 13	Sep 13	Oct 13
19	201205	4	4	4	3	3	3	3	2	2	2	2
20	201206	3	3	3	3	3	3	2	2	2	2	2
21	201207	3	3	3	3	3	3	3	2	2	2	2
22	201208	4	3	3	3	3	3	3	2	2	2	2
23	201209	5	2	2	2	2	2	2	2	1	1	1
24	201210	11	8	4	3	3	3	3	3	3	2	2
25	201211	4	9	7	4	3	3	3	3	3	2	2
26			4	10	7	4	3	3	3	3	3	2
27				4	10	7	4	3	3	3	3	3
28					4	10	7	4	3	3	3	3
29						4	10	7	4	3	3	3
30	Amount of						4	10	7	4	3	3
31	Feedbacks of							4	10	7	4	3
32	future								4	10	7	4
33	deliveries									4	10	7
34											4	10
35												4
36												
37	ROLLING PLAN											
38	→	**62**	**64**	**64**	**65**	**66**	**66**	**67**	**68**	**69**	**70**	**71**
39	→	62	60	50	44	42	39	37	35	34	32	31
40	PROVISION											

Figure 17. Excel-table of the Weibull analysis

As in the figure 18, the average feedback cost is multiplied by the amount of the forecasted feedback. The warranty provision is 600 000 €. The rolling budget for the next 4 quarterlies is calculated as warranty provision, multiplying forecasted feedbacks and average feedback cost.

	Fcst FBs	Avg cost	Total
Warranty provision	1200	500	600 000

Rolling planning	Fcst FBs	Avg cost	Total
Q1/2013	193	500	96 500
Q2/2013	199	500	99 500
Q3/2013	207	500	103 500
Q4/2013	215	500	107 500
			407 000

Figure 18. A Model of the Warranty provision and rolling budget calculations

The general warranty provision should be calculated by quality function in each site. The Quality function and the Controlling function will work together. The Managing Director approves the provision and the Controlling function sends the provision to the bookkeeping department for posting. The provision will be calculated on quarterly basis. If there is a change of the provision, the provision will be posted quarterly in actual figures.

6.2 Simulations in Finland

In Finland there are 6 different profit centers. FK1 and TK15 are the supply units and the other four (FK2, FK3, FK4 and FK5) are component factories.

Four simulations are made for each profit center. Qlikview-parameters and average feedback costs are the same in the every simulation, even if the time frame and the way to calculate future deliveries differ. The parameters are shown in the table 5. In addition, this table is valid for simulations of South Europe and America.

Table 5. The Parameters of Simulations

	Time frame	Future Deliveries	Qlikview parameters	Average Feedback cost
1 Simulation	06/2009-11/2012	Average of old deliveries	Constant	Constant
2 Simulation	06/2009-11/2012	DSB forecast	Constant	Constant
3 Simulation	12/2010-11/2012	Average of old deliveries	Constant	Constant
4 Simulation	12/2010-11/2012	DSB forecast	Constant	Constant

The Qlikview-parameters are tabulated in the tables 6, 7, 8 and 9. These Qlik-view-parameters were used, when the data was collected from Qlikview. **In these figures, the answer for the third sub question is given: What are the Qlik-view-parameters of each profit center?**

Table 6. FK1 Qlikview-parameters

Qlikview parameters, FK1	FB responsibility	Supply line responsibility
	Category	Cat 1. Material reguested, supply line resp.
	Defective Group	Missing, Defective, Damaged, Wrong
	Cause Code	SL-Codes, 16/40
		SL-Customer service/order handling
		SL-Delivery cntr/warehousing
		SL-Engineering non-std
		SL-Engineering std
		SL-Layout engineering
		SL-Listing
		SL-Logistics/Scheduling
		SL-PCM Component
		SL-PCM "Product"
		SL-PCM Variant Configurator
		SL-Purchasing
		SL-Quality
		SL-SAP
		SL-Transport
		SL-Variant Configurator
		SL-Variant Configurator/Components
Time Period	42 months	2009/06-2012/11
	24 months	2010/12-2012/11

Table 7. FK2, FK3 and FK5 Qlikview-parameters

Qlikview parameters, FK2,3,5	FB responsibility	Supply line responsibility
	Category	Cat 1. Material reguested, supply line resp.
	Defective Group	Missing, Defective, Damaged, Wrong
	Cause Code	SL-Codes, 1/40
		SL-Production
Time Period	42 months	2009/06-2012/11
	24 months	2010/12-2012/11

Table 8. FK4 Qlikview-parameters

Qlikview parameters, FK4	FB responsibility	Supply line responsibility
	Category	Cat 1. Material reguested, supply line resp.
	Defective Group	Missing, Defective, Damaged, Wrong
	Cause Code	SL-Codes, 3/40
		SL-Production
		SL-PCM Component
		SL-Vendor
Time Period	42 months	2009/06-2012/11
	24 months	2010/12-2012/11

Table 9. TK15 Qlikview-Parameters

Qlikview parameters, TK15	FB responsibility	Supply line responsibility
	Category	Cat 1. Material reguested, supply line resp.
	Defective Group	Missing, Defective, Damaged, Wrong
	Cause Code	SL-Codes, 18/40
		SL-Customer service/order handling
		SL-Delivery cntr/warehousing/Other
		SL-Delivery cntr/warehousing/Packing
		SL-Delivery cntr/warehousing/Picking
		SL-Engineering non-std (C)
		SL-Engineering std (A)
		SL-Layout engineering
		SL-Listing
		SL-Logistics/Scheduling
		SL-PCM Component
		SL-PCM "Product"
		SL-PCM Variant Configurator
		SL-Purchasing
		SL-Quality
		SL-SAP
		SL-Transport
		SL-Variant Configurator
		SL-Variant Configurator/Components
Time Period	42 months	2009/06-2012/11
	24 months	2010/12-2012/11
	18 months	2011/06-2012/11

In the table 10 the difference between the actual feedback cost and the forecasted (rolling plan) feedback cost is shown. Pay attention to the abbreviations: “average” means that for the future deliveries an average of old deliveries has been used in simulations. DSB means that the official forecast of the future deliveries has been used.

The percentage means how much the actual cost differs from the forecasted cost. The most suitable time period for FK1 seems to be 24 months and an average of old deliveries gives the best result, even if the result is not good. It seems that the forecast is -43 % too low. For FK2 the suitable time period is 42 months using DSB. The forecasting is -12 % too low compared to the actual cost. The most suitable for FK3 is 24 months using an average, but it's not suitable enough. It gives a 63 % too high value, but the actual cost is 63 % smaller than the forecasted cost. For FK4 the best option is 24 months using an average, but forecast gives a -11 % too low value. For FK5, the best option is also 24 months using an average and it gives a 5 % too big value. When calculating and comparing the sum of forecasted costs and the sum of actual costs, it seems that the forecasted cost is -24 % smaller than the actual cost.

Table 10. Difference between actual and forecasted rolling plan in Finland

	FK1	FK2	FK3	FK4	FK5
42 months, average	-44%	-26%	87%	34%	38%
42 months, DSB	-46%	-12%	97%	40%	35%
24 months, average	-43%	-43%	63%	-13%	11%
24 months, DSB	-44%	-32%	69%	-11%	5%

The table 11 shows the percentage differences between the forecasted provisions and the actual provisions for the first 12 months. For FK1, the provision is 46 % too big, if compared to the actual cost. The forecasted provisions are also too high in FK3, FK4 and FK5. In FK2, the provision is -7 % too low. The number of the feedbacks was multiplied with the average feedback cost, but only the year 2013 was examined. S even if the provision is calculated for the next 42 months, only the first 12 months are in this research.

Table 11. Difference between actual and forecasted provision in Finland

	FK1	FK2	FK3	FK4	FK5
Diff, 42 months	46%	29%	327%	130%	232%
Diff, 24 months	75%	-7%	243%	31%	161%

In the table 12 the results of TK15 are tabulated, like in the previous table. 18 months are also calculated, because the quality engineer has noticed that it could be a more suitable period than 42 months or 24 months. Still for the rolling planning, it seems that a time period of 42 months with an average of old deliveries, gives the best result, even though it is -18 % too low.

Table 12. Difference between actual and forecasted rolling plan in Finland

	TK15
42 months, average	-18%
42 months, DSB	-25%
24 months, average	-38%
24 months, DSB	-42%
18 months, average	-30%
18 months, DSB	-36%

The forecasted provisions and the actual costs are compared in the table 13. The best suitable time period is 24 months, but the forecasted cost is still 80 % too high.

Table 13. Difference between actual and forecasted provision in Finland

	TK15
Diff, 42 months	110%
Diff, 24 months	80%
Diff, 18 months	124%

6.3 Simulations in South Europe

In the tables 14, 15 and 16 Qlikview parameters for South Europe profit centers are tabulated. The following parameters have been used when the data was loaded from the Qlikview. **These tables are answer for the third sub question: What are the Qlikview-parameters of each profit center?**

Table 14. IK6 Qlikview-parameters

Qlikview parameters, IK6	FB responsibility	Supply line responsibility
	Category	Cat 1. Material reguested, supply line resp.
	Defective Group	Missing, Defective, Damaged, Wrong
	Cause Code	SL-Codes, 11/40
		SL-Customer service/order handling
		SL-Engineering std (A)
		SL-Listing
		SL-Logistics/Scheduling
		SL-PCM Component
		SL-PCM "Product"
		SL-PCM Variant Configurator
		SL-Quality
		SL-SAP
		SL-Variant Configurator
		SL-Variant Configurator/Components
Time Period	42 months	2009/06-2012/11
	24 months	2010/12-2012/11

Table 15. IK7 and IK8 Qlikview-parameters

Qlikview parameters, IK7, IK8	FB responsibility	Supply line responsibility
	Category	Cat 1. Material reguested, supply line resp.
	Defective Group	Missing, Defective, Damaged, Wrong
	Cause Code	SL-Codes, 1/40
		SL-Production
Time Period	42 months	2009/06-2012/11
	24 months	2010/12-2012/11

Table 16. IK9 Qlikview-parameters

Qlikview parameters, IK9	FB responsibility	Supply line responsibility
	Category	Cat 1. Material reguested, supply line resp.
	Defective Group	Missing, Defective, Damaged, Wrong
	Cause Code	SL-Codes, 1/40
		SL-Production
		SL-Undefined
Time Period	42 months	2009/06-2012/11
	24 months	2010/12-2012/11

The percentage difference between the forecasted rolling planning and the actual cost is introduced in the table 17. The best suitable time period for IK6 is 24 months with an average of old deliveries. The percentage difference is only -4 %. For IK7, the most fitting time frame is 42 months with DSB forecast, but the value is still -22 % too low. The value for the IK8 is 21 % too high and the best fitting time period is 24 months with the DSB forecast. 24 months with an average of old deliveries give the best result for IK9. The difference is only -1 % between the actual and the forecasted rolling plan. If the results of Finland and South Europe are compared, it can be noticed, that the forecast for the rolling plan gives more hitting results than in South Europe than in Finland.

Table 17. Difference between actual and forecasted rolling plan in South Europe

	IK6	IK7	IK8	IK9
42 kk, average	-12%	-22%	100%	10%
42kk, DSB	-18%	-22%	103%	12%
24 kk, average	-4%	-40%	21%	-1%
24 kk, DSB	-8%	-40%	21%	2%

In the table 18, the difference between the provision and the actual cost in South Europeans profit centers is shown. The percentage differences of IK6, IK7 and IK9 are high, so the actual cost and the forecasted provision differ from each other. The forecasted provision is -23 % too low in IK8.

Table 18. Difference between actual and provision in South Europe

	IK6	IK7	IK8	IK9
Diff, 42 months	67%	62%	86%	111%
Diff, 24 months	133%	61%	-23%	100%

6.4 Simulations in America

The Qlikview-parameters for profit centers in America have been introduced in the table 19 and **the answer for the third sub question: “What are the Qlikview-parameters of each profit center?” is given in the table 19**. All cause codes are needed. The profit center, PCM team and the supplier responsibility is also needed, but these are not shown in the table 19, because they could give too much information about the Case Company.

Table 19. AK10, AK11, AK12 and AK13 Qlikview-parameters

Qlikview parameters, AK10, 11, 12, 13	FB responsibility	Supply line responsibility
	Category	Cat 1. Material regueested, supply line resp.
	Defective Group	Missing, Defective, Damaged, Wrong
	Cause Code	All SL-Codes
Time Period	42 months	2009/06-2012/11
	24 months	2010/12-2012/11
	Profit Center	xx
	PCM Team	xx
	Supplier resp.	all

In the table 20, the percentage difference of the profit centers in America is introduced. Difference between the forecasted rolling plan and the actual cost is -8 % in AK10 and the most suitable time period is 42 months with the DSB forecasting. For AK11, the most suitable is 42 months using an average of the old deliveries. The percentage difference is 65 % in AK11. The most suitable for the AK12 is 24 months with an average and the difference is 43 %. For AK13, the most suitable time period is 42 months with the DSB, but the difference is -5 %.

Table 20. Difference between actual and forecasted rolling plan in America

	AK10	AK11	AK12	AK13
42 months, average	-14%	65%	58%	-15%
42 months, DSB	-8%	84%	76%	-8%
24 months, average	-17%	68%	43%	-11%
24 months, DSB	-12%	80%	55%	-5%

As can be seen in the table 21, the percentage difference between the actual and the provision is high in all profit centers. The highest difference is in AK10, 64 % and the smallest is in AK13, 23 %. A 42 months' time frame seems to be better than a 24 months' time frame for all profit centers in America.

Table 21. Difference between actual and provision in America

	AK10	AK11	AK12	AK13
Diff, 42 months	64%	29%	42%	23%
Diff, 24 months	81%	44%	45%	27%

6.5 Control model

The second sub objective was to create a control model for controlling forecasted feedback costs and actual feedback costs. The actual and forecasted feedbacks will be followed in Excel, as well as the average feedback cost. The provision cells will be filled with the number of the forecasted feedbacks and the average feedback cost. In the actual cells will be filled with the number of received feedbacks and the actual average cost. In the *difference cells,* the model automatically calculates the difference between the forecasted and the actual feedbacks. The amount of actual feedbacks and average feedback cost will be reported monthly and the amount of the forecasted feedback and the average feedback cost will be reported quarterly in Excel. The model is simple and easy to fill. The quality engineers in every profit centers will make this follow-up work monthly and the Weibull analysis quarterly. After one year, the follow-up can be checked and estimate, how the forecast has worked. The Control model is in table 22. **The model is the answer for the second sub question: What would be a suitable control model for comparing actual warranty costs and forecasted warranty costs?**

Table 22. Control Model

		PROVISION			ACTUAL			DIFFERENCE	
		Forecasted FBs	Average cost	SUM	Received FBs	Average cost	SUM	PCs	Average FB cost
2013	JAN	45	440 €	19,797 €	54	305 €	16,481 €	-17%	44%
2013	FEB	76	440 €	33,435 €	34	358 €	12,164 €	124%	23%
2013	MAR	34	440 €	14,958 €	76	378 €	28,728 €	-55%	16%
2013	APR	87	460 €	40,020 €	65	435 €	28,275 €	34%	6%
2013	MAY	23	460 €	10,580 €	45	570 €	25,650 €	-49%	-19%
2013	JUN	98	460 €	45,080 €	76	517 €	39,286 €	29%	-11%
2013	JUL	34	425 €	14,450 €	34	450 €	15,300 €	0%	-6%
2013	AUG	65	425 €	27,625 €	76	331 €	25,134 €	-14%	29%
2013	SEP	34	425 €	14,450 €	34	554 €	18,843 €	0%	-23%
2013	OCT	98	480 €	47,040 €	65	650 €	42,250 €	51%	-26%
2013	NOV	34	480 €	16,320 €	23	410 €	9,430 €	48%	17%
2013	DEC	65	480 €	31,200 €	43	390 €	16,770 €	51%	23%
		693	451 €	**314,954 €**	625	446 €	**278,312 €**	11%	1%
								16%	**6%**
2014	JAN	45	412 €	18,540 €	43	360 €	15,480 €	5%	14%
2014	FEB	42	412 €	17,304 €	51	390 €	19,890 €	-18%	6%
2014	MAR	39	412 €	16,068 €	39	512 €	19,968 €	0%	-20%
2014	APR	41	412 €	16,892 €					
2014	MAY	46	412 €	18,952 €					
2014	JUN	52	412 €	21,424 €					
2014	JUL	38	412 €	15,656 €					
2014	AUG	38	412 €	15,656 €					
2014	SEP	43	412 €	17,716 €					
2014	OCT	45	412 €	18,540 €					
2014	NOV	51	412 €	21,012 €					
2014	DEC	32	412 €	13,184 €					
		512	412 €						
								-4%	**-4%**

7 Results and analysis

7.1 The Selected parameters in each profit center

In the table 23 the best suitable parameters of the profit centers in Finland have been listed. **This table is also the answer for the first research question: which parameters will give the best results in the simulations?** The difference percentages of all profit centers have been calculated. If all profit centers would have selected the right time frame and the calculation method for the future deliveries (average of old deliveries or DSB). Then provision the average of all profit centers is 95 %. As can be seen in the table 23, value of FK2 is -7 % too low. The values of other profit centers are too high. The highest is in the FK3, 243 %.

Table 23. The best suitable parameters in Finland

	FK1	FK2	FK3	FK4	FK5	Average
Rolling plan	24 months, average	42 months, DSB	24 months, average	24 months, DSB	24 months, DSB	
Difference, %	-45%	-12%	63%	-11%	5%	0.47%
Provision	42 months, DSB	42 months, DSB	24 months, DSB	24 months, DSB	24 months, DSB	
Difference, %	46%	-7%	243%	31%	161%	95%

If one looks closer, the rolling plan value of FK1, the forecasted cost is -45 % too small. This is caused by cost transfers. Lots of costs have been transferred from other profit centers to FK1, so it seems that forecasting does not regard transfers. The rolling plan forecasting gives good values for the FK2, FK4 and FK5; but the rolling plan value of FK3 is too high. That can be caused by the quality improvements, because the Weibull analysis is based on a historical data and quality improvements are not immediately show in the forecast. Also, if some unexpected quality problems are faced, failures do not show in the forecast. Unexpected failures will be shown in the forecast, after time has advanced.

Why is the provision too high in every profit centers? The forecasting is based on the historical data and it is in the line with the old feedbacks and the future deliveries. That phenomenon will be explained and figured next in the table 24. The numbers of one profit center have been used as an example. In the year 2010, 180 feedbacks were received for the same year shipments. The next year 2011, 112 feedbacks were received for the last year shipments. In the year 2012, 12 feedbacks for the year 2010 shipments were received and in the year 2013 2 feedbacks were received. Still, the Weibull analysis forecasted 28 feedbacks in 2013 for shipments from the year 2010. It can be seen that for the year 2011 shipment, 13 feedbacks were received in year the 2013, but the forecasting gave 54 feedbacks. For 2012 shipments 62 feedbacks were received, but the forecasting gave 162 feedbacks. And for the last shipment in 2013 were 142 feedbacks received, but the Weibull analysis forecasted 204 pieces of feedback. The difference between the forecasted and the actual amount of feedbacks is 105 %. The amount of the future deliveries will also affect the results. It seems that if the amount of future deliveries increase, the amount of feedbacks will also increase. This is logical, but the amount of forecasted feedbacks is much higher than the amount of realized feedbacks.

Table 24. Example of the difference between the amount of the actual and forecasted feedbacks

		Claim Received				
Shipment year		2010	2011	2012	2013	**Forecasted 2013**
	2010	180	112	12	2	28
	2011		221	68	13	54
	2012			144	62	162
	2013				142	204

The important remark is that in this master's thesis, differences of actual provision and forecasted provision were examined by researching the amount of the feedbacks in the year 2013. In real life, the provision is calculated for the next 42 months, so researching on how the actual cost and the forecasted provision match each other, was done examining only first 12 months. That can affect to the result.

In the table 25 the best suitable parameters of the rolling plan and the provision in South Europe are shown. If the average rolling plan of all profit centers in South Europe is examined, one finds out, that the average is -2 %.The provision average of all profit centers is 52 %. If comparing Finland and South Europe, values are considerable better in South Europe. Still, the percentage differences between actual and forecasted provisions are too high.

Table 25. The best suitable parameters in South Europe

	IK6	IK7	IK8	IK9	Average
Rolling plan	24 months, average	42 months, DSB	24 months, DSB	24 months, average	
Difference, %	-4%	-22%	21%	-1%	**-2%**
Provision	42 months, DSB	24 months, DSB	24 months, DSB	24 months, DSB	
Difference, %	67%	61%	-21%	100%	**52%**

In the case of the profit centers in America in table 26, it seems that the average of the rolling plan is 24 %. The average of provision is 40 % too high. The result is better than in Finland or South Europe. The possible reason, why the result is better in the profit centers in South Europe and America is that their products are not that complex than the products produced in Finland.

Table 26. The best suitable parameters in America

	AK10	AK11	AK12	AK13	Average
Rolling plan	42 months, DSB	42 months, average	24 months, average	24 months, DSB	
Difference, %	-8%	65%	43%	-5%	**24%**
Provision	42 months, DSB	42 months, DSB	42 months, DSB	42 months, DSB	
Difference, %	64%	29%	42%	23%	**40%**

7.2 Impact of distributions

During the simulation it has been noticed, that the right distribution enormously affects the result of the simulation and it can be said, that this is the most critical step during simulation. In the appendixes 5, 6 and 7 the selected distributions of all profit centers are tabulated. The most suitable distribution has been marked as green.

One example is introduced, relating to the selected distribution, and explained, how the selected distribution impacts on the result. If the right distribution has been selected, the curve moves along the plots, as sees as in the figure 19. When the forecasting is made according to this curve, the following values can be seen: the amount of the forecasted provision is 292 pieces for the example year and the forecasted rolling plan is 590 pieces.

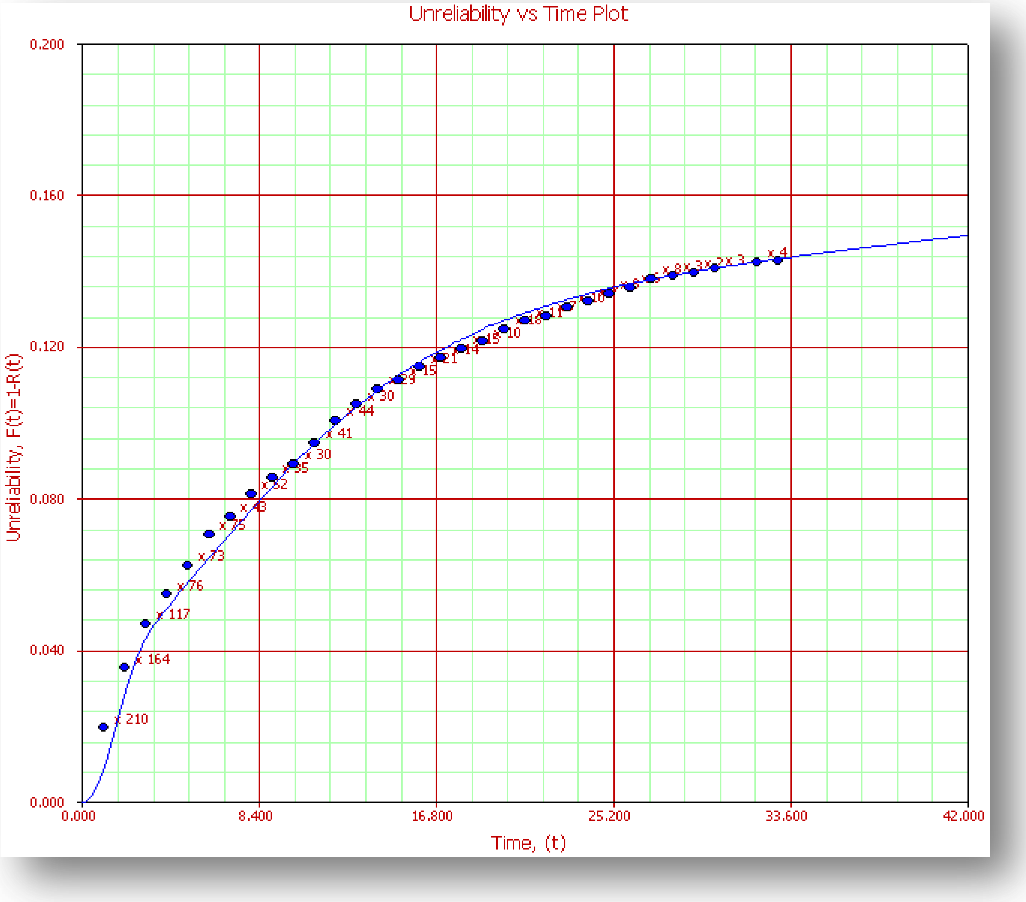

Figure 19. The right selected distribution

If the wrong distribution has been selected, the curve does not move along the plots, as seen as in figure 20. The forecasted provision is 408 pieces and the forecasted rolling plan is 671 pieces. The percentage difference of the forecasted provision is 40 % and the difference of the forecasted rolling plan is 14 %.

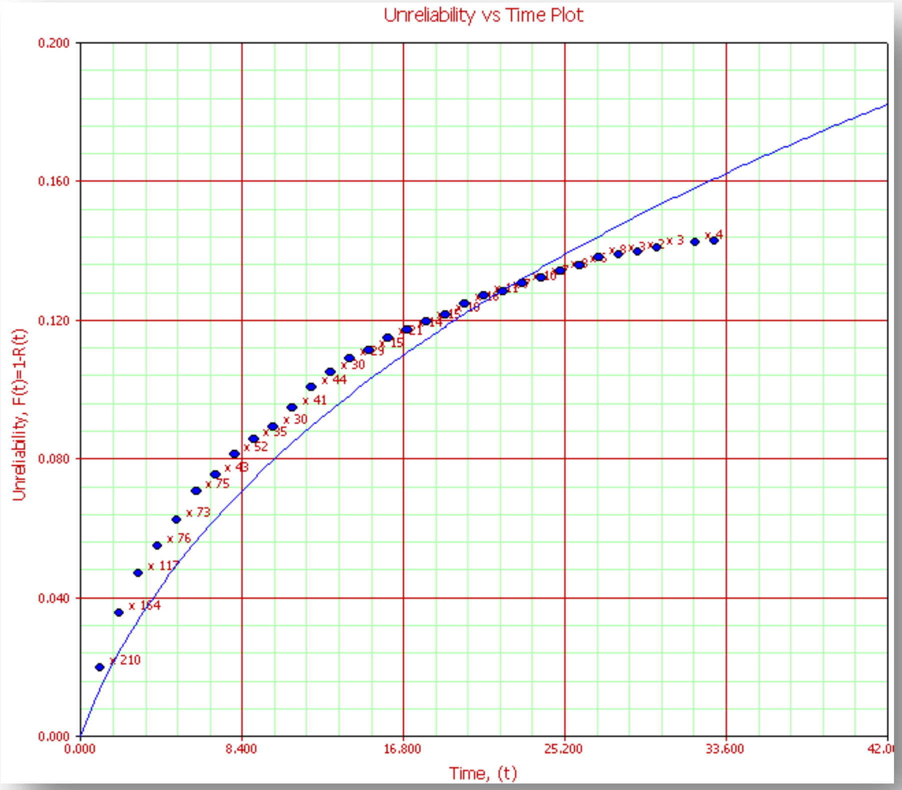

Figure 20. The wrong selected distribution

7.3 Major remarks on the Weibull analysis in the Case Company

Some notification on the Weibull analysis in the Case Company is listed below. First of all, it seems that the values given by the Weibull analysis are too high in almost all supply units and profit centers. The model is based on old, historical data and the model does not immediately or in the short run notice for example quality improving, because it does not show in the analysis. Quality improving or quality decreasing will be shown in the analysis, but after a little time delay. Still, the total value of forecasted rolling plan matches quite well with the actual cost, so if the right time frame will be selected, the Weibull method is a good tool for budgeting and for planning purposes. Instead of provision forecasting, the analysis gives too high costs compared to the actual costs and it seems that the Weibull analysis does not suit this kind of the complex product which the Case Company produces.

The character of the product of the Case Company is complex and the Weibull method was developed for simple products or components. As mentioned in the theoretical part of this thesis, this analysis was developed to homogeneous-data, for example a light bulbs or other simple components. But in this case, the data consists of many products and those products consist of complex components.

If the Company launches a new product, the provision will be forecasted using the Weibull analysis. The problem is that the old data of products is used for forecasting the provision of a new product and the result can’t be right. Also, the theory about the bathtub-curve was introduced in the theoretical part. The failure rate of products in their early life period is higher than products in their period of an useful life. Products in different stage of the equipment’s life should be handled separately, but still, the whole data is in the same group. That will affect the result as well.

Many people use the Weibull analysis in the Case Company and it was noticed, that some people can’t use this software right. So human errors are risky for the Weibull analysis and small mistakes can spoil the whole analysis. But this problem can be solved by arranging training sessions. The training does not remove the problem that the simulation does not give the right results.

The result of this master’s thesis shows that the simulation works better in South European and American profit centers. This can be caused by a difference of complexity in products. The process used in south European profit centers is a so called A-process, which means, products are always of the same kinds. This means that the products are simpler than C-process products. In contrary to European and American profit centers, the process in Finland is a C-process and thus, products are more complex. So failures of products are more difficult to forecast, because products will be produced according to the customer’s requirements.

Is the method a suitable method for the Case Company? The method does not work perfectly, because the character of the business and also, because this method has not been developed for that kind of products. Still, any forecasting method does not give 100 % right results and small difference between actual and forecasted costs can be accepted. It seems that the method does not work in its current state, but it would work better, if the company could consider making their forecast for every product separately in the future. Also warranty costs will affect the profitability of the products, so if the products will be analyzed separately, the profitability of each product would be more visible. It is not worth to abandon this method immediately, because the results of some profit centers are quite correct. It should be remembered, that this research has been made, in the case of the provision, only for the first 12 months, even though the Case Company uses 42 months. Also there is another variable, the average feedback cost. So if the amount of forecasted feedback is too high, the average feedback cost can equalize the provision, since the Case Company tries to forecast the cost of the provision and the rolling plan, not actual the amount of feedbacks. One suggestion is that the Case Company would observe results given by the Weibull analysis for example one year, but another and better suggestion is that the Case Company should try to make simulations for the product level not the profit center level. But if a product level analysis does not work, it is worth considering abandoning the Weibull method and to trying a simpler system. The forecasting should be made separately for new products, or new products should be excluded, because they distort the results. So the answer to the question is: the Case Company could observe results of the simulation, for example one year, and then they should consider, if they change to the product level analyzing. Also if the information about costs will be given to accounting in the total cost level, the mistake of the cost will even out, because other profit centers give too high or low values.

As mentioned in the chapter 3.7 *uncertainty on forecasting*, the uncertainty of the future will also affect the result. Even if, the DSB forecasting is available, it is not 100 % sure and if it comes to the average of future deliveries, it is also an uncertain way to estimate future deliveries, because it is based on historical data. Also, the natural fluctuation of claims will affect the result.

The Case Company didn’t have any model for following and controlling actual and forecasted cost. The second sub objective was to create a simple Excel-model for the following cost. This model was introduced in the chapter 6.5. Quality engineers will maintain control models and observe actual and forecasted costs.

Last but not least the third sub objective was to document the Qlikview-parameters of each profit center. The answer for this task is in the chapters 6.2-6.4 and in the tables 6, 7, 8 and 9 for profit centers in Finland and tables 14, 15 and 16 for profit centers in South Europe and table 19 for profit centers in America. The simulations have been made according to these parameters.

Summit (2012, 451-464) researched, how much data is needed for getting accurate results. He noticed that at least two years of data is needed, because usually a large number of feedbacks were received after two years of shipment. Only 5 % of feedbacks were received in the first year. In the case of the Case Company, most of the feedbacks were received in the first year, more precise, during the first six months. A smaller amount of feedbacks were received in the second and in the third year, but still at least 18 months should be used in the simulations, because feedbacks will be received during that time frame and software Weibull++ can’t make a right forecasting, if only the first 12 months are examined. So the result of Summit’s study and this master’s thesis is that more than one-year data is needed for a proper analysis and a parameter estimation.

8 Conclusions

Quality has in general and in case of the Case Company, a significant impact on the economy of the Company. For the Case Company, quality is the most important competitive factor. Failures, problems in processes, scrap, rework costs and warranty costs affect quality costs and all of this is affecting the profitability of the company. Measuring the Cost of Poor Quality is important, because it helps to understand the gravity of quality problems and more over shows opportunities for improvements. Reliability is one part of quality and if the product is reliable, it could be said that the quality is good. The Bathtub-curve is a one tool, which demonstrates the behavior of products in their life cycle. When a product is launched, more failures can be expected and the reliability is lower, but a time goes on, the failure rate will decrease and the reliability will increase. As the wear-out life failure rate will increase again. All new products should be handled separately in warranty forecasting analysis.

Warranty costs are unpredictable future costs and it is important to manage them. Warranty strategies are based on minimizing costs. When improving reliability and quality control, the warranty servicing costs will decrease. Lots of tools are available for warranty forecasting, but most of them are too complex. Also, only few softwares are available for the company purposes.

The Company has had problems to forecast the future feedback costs and a solution for that problem was sought by this master's thesis. The main objective of this study was researching, if the Weibull method is a suitable method for the Case Company. A total of 56 simulations were made in profit centers of Finland, South Europe and America, using the Weibull method. The analysis gave a too high provision, compared to the actual provision. But a limitation in that regard is that only the first 12 months were examined. The rolling plan seems to work better, so it is a workable tool for planning purposes. The main reason, why the Weibull method does not work properly in the Case Company is, that model is based on historical data. Because of that quality improving does not show in the analysis. Furthermore, this method was planned for simpler products that the Case Company manufactures. The method is optimal for researching homogeneous-data. Simulations worked better in South Europe and America, because both factories produce so called A-process products, as opposed to Finland, which produces C-process products. Suggestions for the future are that Company should make their simulations in the specific level, for example product level. If the Company makes their Weibull analysis in the product level, the profitability of a single product would be more visible. Also, new products could be analyzed separately of old products, because in the early life of a product, the failure rate is higher, but the failure rate will decrease as time goes on. If all products are handled together, the result will distort.

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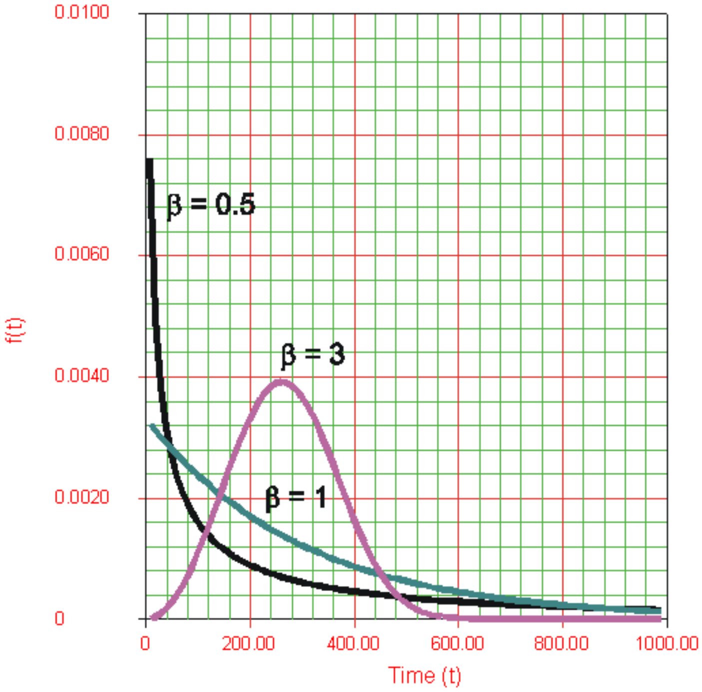
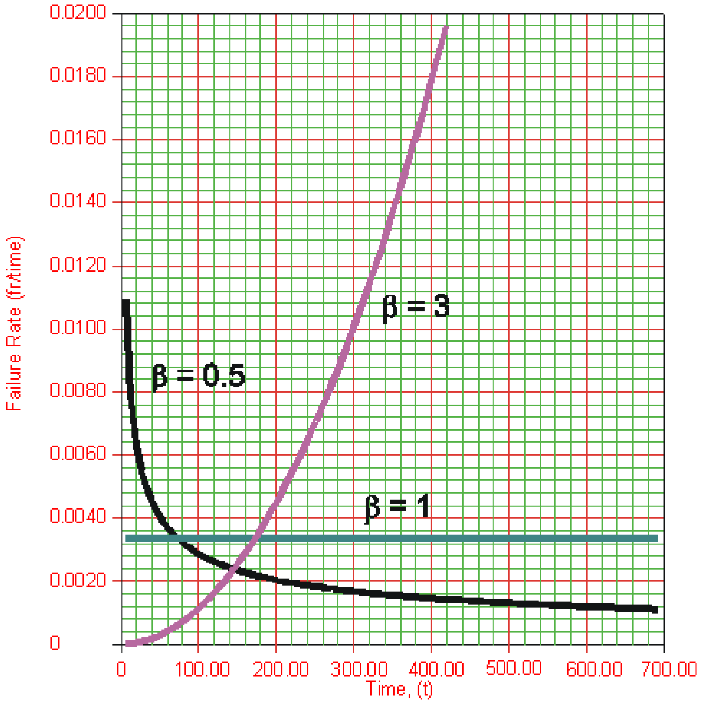
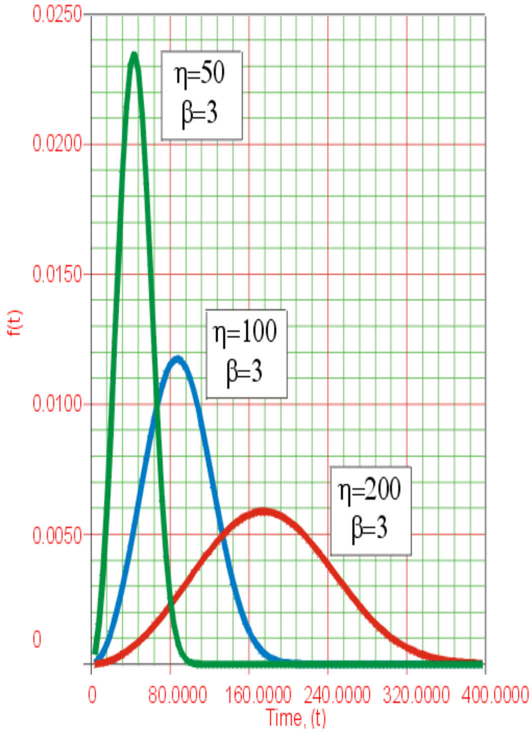
Appendix 1- The effect of β on the pdf (Reliability Engineering Resources 2005)



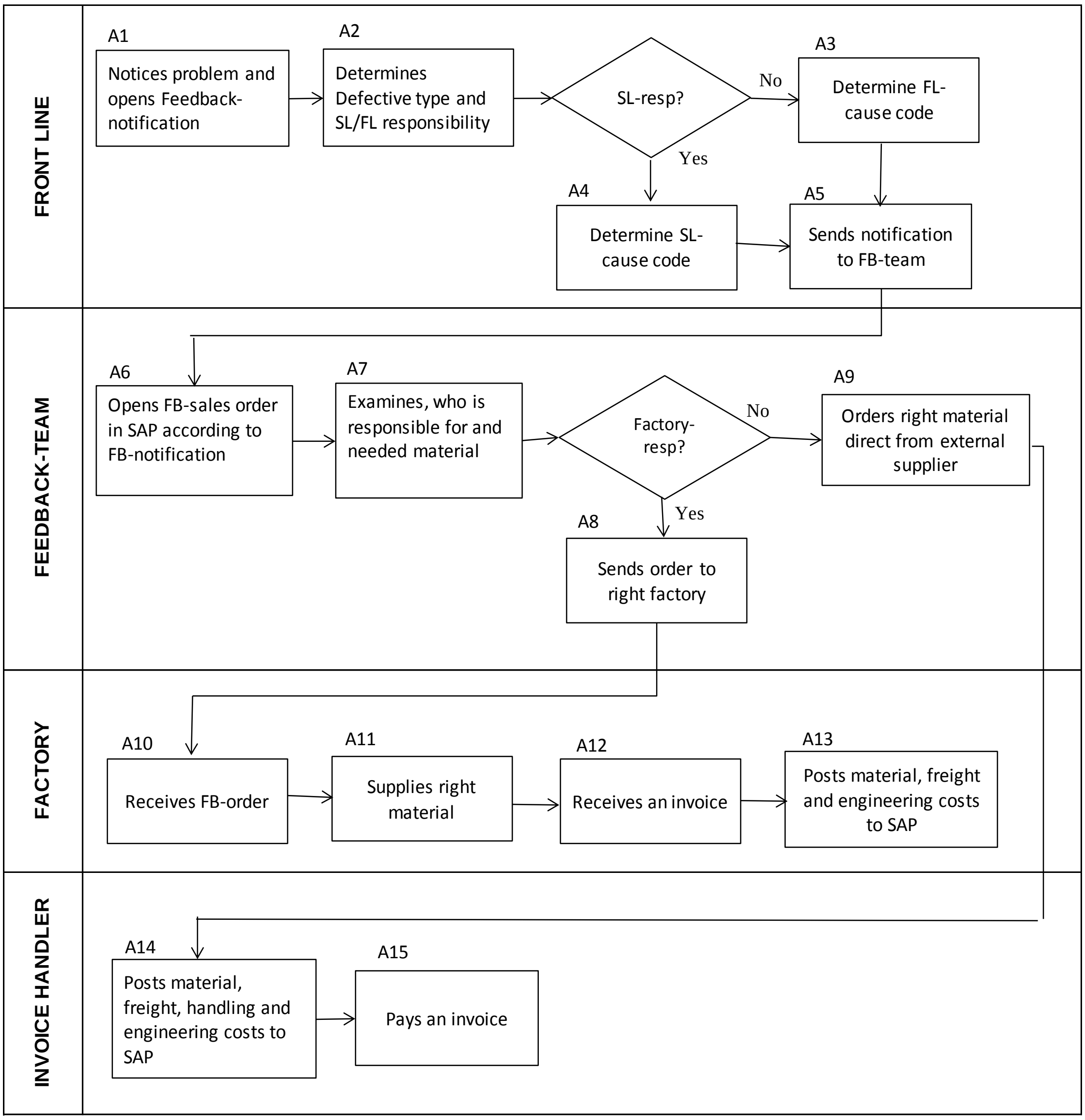
Appendix 2. The effect of β on the Weibull Failure Rate Function (Reliability Engineering Resources 2005)



Appendix 3. The effects of η on the Weibull pdf for a common β (Reliability Engineering Resources 2005)



Appendix 4. Feedback-process



Appendix 5. Distributions of profit centers in Finland

FK1	
42kk, average	3-subpopulation Mixed-Weibull
42kk, DSB	3-subpopulation Mixed-Weibull
24kk, average	3-subpopulation Mixed-Weibull
24kk, DSB	3-subpopulation Mixed-Weibull
FK2	
42kk, average	3-subpopulation Mixed-Weibull
42kk, DSB	3-subpopulation Mixed-Weibull
24kk, average	3-parameter Weibull
24kk, DSB	3-parameter Weibull
FK3	
42kk, average	Generalized Gamma
42kk, DSB	Generalized Gamma
24kk, average	2-subpopulation Mixed-Weibull
24kk, DSB	Generalized Gamma
FK4	
42kk, average	3-subpopulation Mixed-Weibull
42kk, DSB	3-subpopulation Mixed-Weibull
24kk, average	3-parameter Weibull
24kk, DSB	3-parameter Weibull
FK5	
42kk, average	3-subpopulation Mixed-Weibull
42kk, DSB	3-subpopulation Mixed-Weibull
24kk, average	3-parameter Weibull
24kk, DSB	3-parameter Weibull
TK15	
42kk, average	3-subpopulation Mixed-Weibull
42kk, DSB	3-subpopulation Mixed-Weibull
24kk, average	3-subpopulation Mixed-Weibull
24kk, DSB	3-subpopulation Mixed-Weibull
18kk, average	3-parameter Weibull
18kk, DSB	3-parameter Weibull

Appendix 6. Distributions of profit centers in South Europe

IK6	
42kk, average	2-subpopulation Mixed-Weibull
42kk, DSB	2-subpopulation Mixed-Weibull
24kk, average	3-subpopulation Mixed-Weibull
24kk, DSB	3-subpopulation Mixed-Weibull
IK7	
42kk, average	2-subpopulation Mixed-Weibull
42kk, DSB	2-subpopulation Mixed-Weibull
24kk, average	3-subpopulation Mixed-Weibull
24kk, DSB	3-subpopulation Mixed-Weibull
IK8	
42kk, average	3-subpopulation Mixed-Weibull
42kk, DSB	3-subpopulation Mixed-Weibull
24kk, average	3-subpopulation Mixed-Weibull
24kk, DSB	2-subpopulation Mixed-Weibull
IK9	
42kk, average	3-subpopulation Mixed-Weibull
42kk, DSB	2-subpopulation Mixed-Weibull
24kk, average	3-subpopulation Mixed-Weibull
24kk, DSB	3-subpopulation Mixed-Weibull

Appendix 7. Distributions of profit centers in America

AK10	
42kk, average	3-subpopulation Mixed-Weibull
42kk, DSB	3-subpopulation Mixed-Weibull
24kk, average	4-subpopulation Mixed-Weibull
24kk, DSB	4-subpopulation Mixed-Weibull
AK11	
42kk, average	3-subpopulation Mixed-Weibull
42kk, DSB	3-subpopulation Mixed-Weibull
24kk, average	2-subpopulation Mixed-Weibull
24kk, DSB	2-subpopulation Mixed-Weibull
AK12	
42kk, average	3-subpopulation Mixed-Weibull
42kk, DSB	3-subpopulation Mixed-Weibull
24kk, average	2-subpopulation Mixed-Weibull
24kk, DSB	2-subpopulation Mixed-Weibull
AK13	
42kk, average	3-subpopulation Mixed-Weibull
42kk, DSB	3-subpopulation Mixed-Weibull
24kk, average	2-subpopulation Mixed-Weibull
24kk, DSB	2-subpopulation Mixed-Weibull