DAS Departamento de Automação e Sistemas
CTC Centro Tecnológico
UFSC Universidade Federal de Santa Catarina

Reliability Analysis and Visualization of product's lifetime behavior

Relatório submetido à Universidade Federal de Santa Catarina

como requisito para a aprovação na disciplina

DAS 5511: Projeto de Fim de Curso

Roberta Silva Yakabi

Würzburg, Janeiro de 2015

Reliability Analysis and Visualization of product's lifetime behavior

Roberta Silva Yakabi

Esta monografia foi julgada no contexto da disciplina
DAS5511: Projeto de Fim de Curso
e aprovada na sua forma final pelo
Curso de Engenharia de Controle e Automação

Prof. ***Acires Dias***

____
Assinatura do Orientador

Banca Examinadora:

Dipl.-Wirtsch.-Ing. Danny Koellmann
Orientador na Empresa

Prof. Acires Dias
Orientador no Curso

Prof. Ubirajara Franco Moreno
Avaliador

Artur Mendes Cook
Guilherme Fariello Interlandi
Debatedores

Acknowledgements

I would like to especially thank, Danny Koellmann, for the great opportunity to work on such a challenging project. He was an amazing supervisor who was always concerned to give me all the support I needed. I really appreciate his patience with me and all the help and good ideas he had to solve many problems. He is an exceptional engineer and it was a privilege to work with him.

I would like to thank Professor Acires Dias for all the support he gave me during this project, I am very grateful and glad to had him as my supervisor as well. I also would like to thank the Professors Werner Kraus Junior, Ricardo José Rabelo and Hector Bessa Silveira for the whole bureaucratic support and patience with the students.

I want to thank my family and friends, especially my sister Talita, for always encourage me and for believing in me even during the most difficult moments. I would like lastly, to give and extra thank to my parents for all the support they always gave me over the years, everything I ever achieved, I owe them.

Resumo

A concorrência no mercado globalizado exige o desenvolvimento de produtos com alta confiabilidade e boa qualidade e serviços. Atualmente em todo o mundo, bilhões de dólares são gastos todos os anos para criar produtos confiáveis e de boa qualidade. Princípios de qualidade e confiabilidade são aplicados em vários setores da economia, e para cada um destes setores, há métodos, princípios e procedimentos adaptados de qualidade / confiabilidade, a fim de satisfazer cada necessidade específica [9].

Bosch Rexroth AG, subsidiária do grupo Bosch, é um dos principais fornecedores mundiais de tecnologias de acionamento e controle. A sede da Bosch Rexroth AG está localizado na cidade de Lohr am Main, na Alemanha, e é a principal responsável pela produção e manutenção de sistemas hidráulicos, acionadores e comandos elétricos da Bosch Rexroth na Europa. A empresa tem experiência mundial nos setores de Mobile Applications, Machinery Applications and Engineering, Factory Automation, e desenvolve sistemas e serviços personalizados aos seus mais de 150.000 clientes em todo o mundo [2].

A Bosch Rexroth apresenta um enorme banco de dados com informação detalhada de seus produtos dos últimos 20 anos. Todos esses dados, que contém informações sobre as entregas e reclamações de pedidos de produtos, podem ser usados agora para realizar análise de dados de campo a fim de obter informações sobre o comportamento da vida dos produtos. Com a análise de dados de campo, informações importantes sobre os produtos são avaliadas e podem ser usados para melhorar a sua qualidade e confiabilidade.

O principal objetivo deste projeto foi desenvolver um conceito de avaliação de confiabilidade e sua implementação em uma ferramenta de software para visualização e avaliação de dados de campo, integrado com análise de Weibull, a fim de ajudar os departamentos de Qualidade e Serviço da Bosch Rexroth.

A ferramenta de análise de dados de campo foi desenvolvida com a linguagem de programação Python. A ferramenta apresenta diferentes abordagens de visualização de falhas como a combinação de um gráfico com barras e linha e análise de bolhas (gráficos de bolhas). A avaliação dos dados de campo ajuda a obter melhores resultados para as análises de Weibull, e portanto melhores

indicadores de confiabilidade e melhor prognóstico de falha dos produtos da Bosch Rexroth. Os resultados obtidos podem ajudar a empresa a melhorar a qualidade e confiabilidade de seus produtos no futuro.

Este trabalho apresenta o relatório desenvolvido durante o Projeto de Fim de Curso realizado pela estudante Roberta Silva Yakabi no Departamento de Gerenciamento e Métodos de Qualidade da Bosch Rexroth em Würzburg, na Alemanha.

Capítulo 2 introduz a empresa onde o projeto foi desenvolvido, apresenta uma visão geral da estratégia de confiabilidade da Bosch Rexroth e é seguido por suas atividades atuais com base em avaliações de dados de campo. No final do capítulo, os principais objetivos do projeto são explicados.

O capítulo 3 apresenta a base teórica necessária para melhor compreender o projeto. Neste capítulo há uma breve revisão de conceitos básicos de qualidade, princípios básicos de confiabilidade e design for reliability. Uma introdução à análise de Weibull também é explicado, a fim de dar ao leitor um melhor contexto do projeto e como o comportamento do tempo de vida de produtos podem ser analisados e as medidas de confiabilidade adquiridas. The seven basic tool for root cause analysis são explicados brevemente a fim de mostrar as possibilidades de visualização de falhas de produtos e avaliações de dados de campo.

Capítulo 4 apresenta o conceito de avaliações de confiabilidade e a descrição do problema para este projeto. Na seqüência, a importância das avaliações de dados de campo para análise de Weibull é avaliada. Por último, a solução proposta como uma ferramenta de software para análise de dados de campo é descrita.

Capítulo 5 apresenta a implementação da ferramenta.

Capítulo 6 mostra os resultados obtidos com a ferramenta desenvolvida.

O Capítulo 7 apresenta a conclusão e as perspectivas deste projecto e sua importancia para a Bosch Rexroth.

Abstract

The global market competition demands manufacturers to develop products with high reliability and good quality and services. Nowadays, all over the world, billions of dollars are spent every year to create reliable and good quality products. Quality and Reliability principles are applied in various sectors of the economy, and for each of these sectors, there are tailored quality/reliability methods, principles and procedures in order to satisfy its specific need [9].

Bosch Rexroth AG is one of the world's leading providers of drive and control technologies. The headquarter of Bosch Rexroth AG is located at the city of Lohr am Main, Germany, and is the main responsible for the production and maintenance of hydraulics, electric drives and controls of Bosch Rexroth in Europe. It has global application experience in the market sectors of Mobile Applications, Machinery Applications and Engineering, Factory Automation to develop tailored system solutions and services. The company supplies its more than 150.000 customers all over the world, hydraulics, electric drives and controls, gear technology, and linear motion and assembly technology all from one source [2].

Bosch Rexroth has a huge database with detailed product information from the last 20 years. All this data, which contains information about deliveries and claims of products, can be used now to make field data analysis in order to get information about the products lifetime behavior. Due to field data analysis, important information about the products is retrieved and can be used to improve their quality and reliability.

The main goal of this project was to develop a concept of reliability evaluations and its implementation in a software tool for field data visualization and evaluation, integrated with Weibull analysis, in order to support Quality Management and Service Departments of Bosch Rexroth.

The field data analysis tool was developed with the open source programming language Python. The tool presents different approaches of failure data visualization as a combination of bar and line chart and bubble analysis. The assessment of the field data helps to get better results for the Weilbull evaluations, therefore better reliability indicators and better failure prognosis of Rexroth products. The results achieved can help the company to improve the quality and reliability of their products in the future.

Keywords: *Reliability, quality, field data evaluation, lifetime behaviour, Weibull analysis, Bubble analysis.*

Contents

List of figures

Simbology

DC: Drive & Control Company Bosch Rexroth

DfR: Design for Reliability

PDF: Probability Density Function

MTTF: Mean Time to Failure

PDCA: Plan-Do-Check-Act

RADAR: Results, Approach, Deploy, Assess and Refine

DMAIC: Define, Measure, Analyse, Improve, and Control

DFSS: Design for Six Sigma

MVC: Model-View-Controller

ERP: Enterprise Resource Planning

OEM: Original Equipment Manufacturer

TCO: Total Cost of Ownership

Chapter 1: Introduction

The global market competition demands manufacturers to develop products with high reliability and good quality and services. Nowadays, all over the world, billions of dollars are spent every year to create reliable and good quality products. Quality and Reliability principles are applied in various sectors of the economy, and for each of these sectors, there are tailored quality/reliability methods, principles and procedures in order to satisfy its specific need [9].

Given the scenario of globalization, in which the market demands new products faster, low-priced, more reliable and with good quality; companies are increasingly searching ways to reduce production costs, in order to remain competitive. It is estimated that the costs of maintenance comprises 8 to 12% of production costs [1]. One advantage of reliable products is the reduction of costs for unplanned maintenance and repairs, and in consequence, the production costs of customers are lower.

1.1: Motivation

Bosch Rexroth AG is one of the world's leading providers of drive and control technologies. The company has stored for more than 20 years a huge database with detailed product information regarding delivery and claim.

The main motivation is to learn from the past and use the information stored over the past years to analyse the reliability of products and visualize products lifetime behavior.

Due to products lifetime analysis, it is possible to obtain reliability measurements, which can be used consequently to improve quality of Bosch Rexroth products and services. Furthermore, reliability evaluations result in a more accurate failure prognosis.

1.2: Structure of the Thesis

This report presents the work developed by the student Roberta Silva Yakabi during her internship in the Central department of Quality Management and Methods of Bosch Rexroth.

Chapter 2 introduces the company where the project was developed. An overview of the strategy for reliability at Bosch Rexroth is presented followed by its current activities based on field data evaluations. In the end of the chapter, the main objectives of the project are explained.

Chapter 3 presents the theoretical basis necessary to understand the background of this project. In this chapter a brief review of quality basics, basic principles of reliability and Design for Reliability are presented. An introduction to Weibull analysis is also explained in order to give the reader a better context of the project and how lifetime behavior of products can be analysed and reliability measurements acquired. The seven basic tool for root cause analysis are also briefly explained in order to show the possibilities of visualization of products failures and field data evaluations.

Chapter 4 has the concept of reliability evaluations. The problem description for this project is presented and leads to the study of data visualization possibilities that can be used to visualize products failures. In the sequence, the significance of field data evaluations for Weibull analysis is evaluated. Lastly, the proposed software tool solution for field data analysis is described.

Chapter 5 presents the tool implementation.

Chapter 6 shows the results acquired with the tool developed.

Chapter 7 presents the conclusion and outlook of this project and its significance for Bosch Rexroth.

Chapter 2: Bosch Rexroth and Proposed Solution

The headquarter of Bosch Rexroth AG is located at the city of Lohr am Main, Germany, and is the main responsible for the production and maintenance of hydraulics, electric drives and controls of Bosch Rexroth in Europe.

For more than 20 years, the company has stored a huge amount of detailed information on deliveries, repairs, and maintenance of its products. Given the scenario, a proposed solution for reliability analysis of field data is presented. The company can now learn from the past and use all this collected information to generate new business cases, such as maintenance contracts as an example, also obtain quality and reliability measurements, and consequently improvement of its products.

In this chapter, the company is described, followed by its strategy for reliability, the maintenance strategy, and the proposed solution.

2.1: About Bosch Rexroth AG

Bosch Rexroth AG, known as The Drive & Control Company (DC), part of Bosch Group, is one of the world's leading providers of drive and control technologies. It has global application experience in the market sectors of Mobile Applications, Machinery Applications and Engineering, Factory Automation to develop tailored system solutions and services. The company supplies its more than 150.000 customers, hydraulics, electric drives and controls, gear technology, and linear motion and assembly technology all from one source [2].

Bosch Rexroth is commited to the total lifecycle of its products, efficient from inicial concept to service. The products groups of DC are: Linear Motion Technology; Industrial Hydraulic Controls; Industrial Hydraulic Cylinders; Assembly Technology; Transmission Units; Electric Drives and Controls; Mobile Controls; Power Units, Manifolds, and Hydraulic Accessories; Compact Hydraulics; Pumps and Motors; Mobile Electronics; Large Hydraulic Drives [4].

The company has a history of more than 200 years. DC has more than 33,700 associates (24.800 in Europe, 3.100 in America and 5.800 around Asia, Pacific and

Africa), 56 manufacturing locations and customization sites in 22 countries, in addition to sales and service network throughout more than 80 countries all over the globe [3].

In 2014, Bosch Rexroth achieved total sales of approximately € 5.6 billions, represented € 3.3 billions by Europe, € 1 billion by America and € 1.3 billions by Asia, Pacific and Africa. The total research and development spent was € 340 millions, about 6.1% expenditure as a percentage of sales [3].

2.2: Strategy for reliability at Bosch Rexroth

Robert Bosch once said, "It has always been an unbearable thought to me that someone could inspect one of my products and find it inferior in any way. For that reason, I have constantly tried to produce products which withstand the closest scrutiny – products which prove themselves superior in every respect."

Since the beginning Bosch stands for quality and reliability, and the subsidiary Rexroth also embraced the principles of Bosch and adopted a reliability management strategy through the whole product life cycle.

For the Bosch Group, reliability is a product characteristic that must be designed systematically, considering the cause and effect relationships. Therefore, the reliability of Bosch Rexroth products is determined in the development phase, since the design has an important role on the product reliability [6]. There is a range of approaches to achieve reliability in a product that are applied in the design phase. Those approaches are better explained on the third section of Chapter 3, Design for Reliability.

The quality of the products, as well as its reliability, must be ensured on the launch of series production. Thus, the products are subjected to trials during their development, which is a test conducted on a technical product to verify and validate quality features, such as reliability. The trials are destinated to confirm that the requirements have been satisfied and the reliability of the product has also been proved [6].

Finally, observations of the product behaviour in the field are part of the requirements in order to complete the reliability management over the product life cycle. With the field data evaluations it is possible to proof that the targets defined in the development phase were achieved. The analysis of field data can indicate causes of unreliability and also helps to define measures to improve the product. [5].

2.3: Current activities based on field data evaluations

The Service department of Rexroth in Lohr am Main is responsible for maintenance and repairs of electric products. In recent times, they recognized that the company could expand its business with products maintenance and repairs. As a result to gain new service contracts and intensify the relationship with their customers, they also provide maintenance advice.

The department of Quality Management and Methods of Bosch Rexroth has been using the Weibull distribution to do cause analysis and to determine reliability parameters. In order to produce an accurate and reliable maintenance advice, a Weibull analysis based on the data stored over the last years was established as standard method, followed by a failure forecast for the Rexroth's products in the customer application for the next years. In sum, with the failure forecast, the customer's operating data and costs, it is possible to compare the predicted costs of preventive services and reactive maintenance services.

The maintenance advices proposed by the Service department of DC are either corrective or preventive maintenance. In accordance with the standards norm on maintenance terminology:

"Preventive maintenance: maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item. (…) Corrective maintenance: maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function." [7]

The products of Rexroth have high reliability standards for its intended lifetime. As the products get older and start the wear out phase, failures are more frequently occurring, but even though their intended lifetime have exceeded, they are kept in operation. Rexroth advises preventive maintenance to reduce the product high probability of failure and reduce losses related to operation downtime.

2.4: Objectives of the project

The main goal of this project is to develop a concept of reliability evaluations and its implementation in a software tool for field data visualization and evaluation in order to support quality, engineering, service, production, and sales department. Figure 1 shows a scheme of the proposed solution:

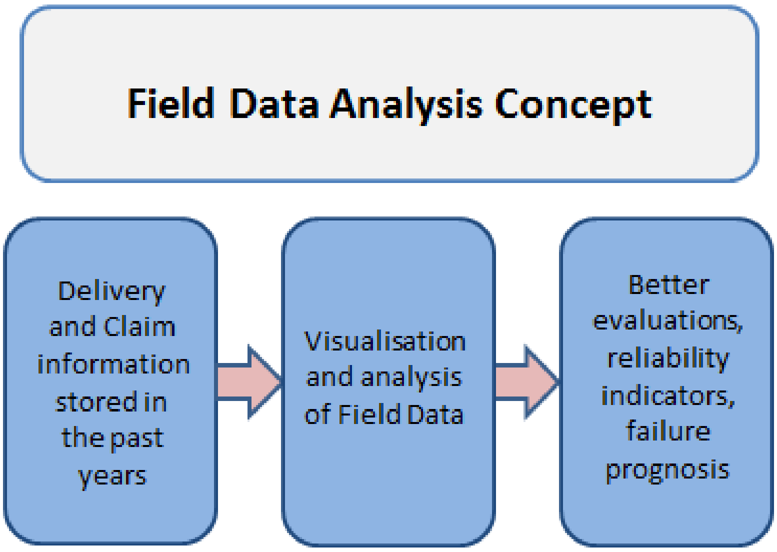

Figure 1: Proposed solution

The main reasons to make the field data evaluations at DC are:

- Evaluation of product reliability: determination of the status quo regarding reliability (e.g. Weibull)
- Prognosis of future field failures: assessment of the risks (e.g. warranty-related costs)
- Cause study: statistical analysis of field data from SAP in order to identify main causes (failure mechanisms, potential weak points) of field failures and also to quantify these types of failures

The field data analysis tool will provide distinct approaches of field data visualization, represented by different types of charts which will show the field failures over a time period. The assessment of the field data will help to get better results for the Weilbull evaluations, therefore better reliability indicators and better failure prognosis. The tool will also help to identity family patterns, main causes of field failures and visualize the heterogeneity of the population.

Chapter 3: State of Art

Quality and reliability are strongly related. The level of quality produces its equivalent reliability, since reliability is achieved with quality standards [9].

In this chapter, a brief review of quality and reliability basics are presented, and also a review of the techniques and background knowledge needed for this project.

3.1: Quality basics

According to ISO 9000 – 2015, “The quality of an organization’s products and services is determined by the ability to satisfy customers and the intended and unintended impact on relevant interested parties.

The quality of products and services include not only their intended function and performance, but also their perceived value and benefit to the customer.”

Quality contributes to business success and quality products not only decrease the risk and cost of replacing faulty products but also help to keep customer satisfaction and loyalty.

There are many definitions for quality [9]:

- A degree of excellence
- Conformance to requirements
- Totality of characteristics which act to satisfy a need
- Fitness for use
- Fitness for purpose
- Freedom from defects
- Delighting customers

When the quality requirements are not achieved, a way to improve the quality is using problem solving methods.

There are four basic phases of Analytical Problem Solving to prevent quality problems [10]:

1. Describe the Problem → scope the problem and describe its symptoms precisely: create a clear Problem Statement, define the problem's scope (Cause and Effect Diagram, Process Flow Diagram), have an organized list of Symptoms (Is/Is Not Matrix).
2. Identify and Verify the Root Cause → create hypotheses about what is possible to be the root cause and on the sequence test the hypotheses to verify which one is correct: Theoretical tests (Logical fit of the data, Comparative Analysis), Statistical tests (Hypothesis testing, Probability), Experimental tests.
3. Decide how to eliminate the Root Cause → decide what is the best solution to your problem by identifying a number of alternatives and choosing the best one.
4. Implement the Solution → Plan and implement the solution in detail and carefully, considering the forces at work that can be an impediment to your success and deal with them.

There are a few quality improvement methodologies that can be used as possibility for the continuous quality improvement of products, processes and services in organizations [11]:

- The PDCA (Plan-Do-Check-Act) cycle is a fundamental concept of continuous-improvement processes;
- RADAR (Results, Approach, Deploy, Assess and Refine) matrix provides a structured approach assessing the organizational performance;
- DMAIC (Define, Measure, Analyse, Improve, and Control) is a systematic and fact based approach that provides framework of results-oriented project management;
- DFSS (Design for Six Sigma) is a systematic and structured approach to new products or processes design, which is focused on problem prevention.

3.2: Basic Principles of Reliability

Reliability is the property of a product to achieve a required function, in a specified operating range, during a specified service time [6].

Usually for customers, reliability is an important desired characteristic of the product, and the guarantee of a reliable product is a crucial point for business success. Experimental tests to validate reliability combined with new approaches are necessary to obtain the desired reliability. Design for reliability approaches, integrated with arithmetical prediction of reliability and its optimization moved the reliability concern to an earlier phase on the development of the product, so that overall costs could be reduced [5].

Reliability analysis can be used for many reasons in different phases of the product, from the development until after sales:

- Product development:
    - Calculation of product lifetime
    - Reduction of development time and costs (reduce tests efforts)
    - Minimization of failure costs
    - Early detection of weaknesses
- Series Production:
    - Minimization of failure costs
    - Early detection of weaknesses
    - Improvement of product quality
- After sales:
    - Calculation of expected failure rates for products
    - Calculation of expected failure rates for customers (failure costs)
    - Development of solutions to reduce maintenance costs

3.3: DfR – Design for Reliability

Design for Reliability – DfR, is a systematic, preventive approach during the development of the product, which is based on the understanding of cause and effect relatioships, in order to guarantee that the product design has the product characteristic "Reliability" [12].

There are different approaches to achieve reliability of a product, which are described as follows, and the common factor they all share is that the reliability achieved must be verified and validated.

1. Test-based Design: the design phase is focused on the design of the functionality. Any problem regarding to reliability is detected with tests and then repaired with a design measure. More tests are later applied to verify if the repair measure was effective. The "Design→Test→Fix→Test" cycle repeats uninterruptly until the reliability is proven with a test.
2. Experience-based Design: this approach assumes expertise in the reliability behavior of earlier products and knowledge about what is relevant to be transferred. The expertise in the reliability behavior is based on tests made previously and also on the evaluation of field data.
3. Overdesign-based design: the design here is implemented to ensure that the reliability requirements are exceeded. The goal of this approach is to achieve a large safety margin between the stress and the strength. The selection of this safety margin is derived from experience or from norms and regulation.
4. Norm-and regulation-based design: in this approach, the design is accomplished in accordance with the specifications and/or assessment guidelines of norms and regulations that are relevant.
5. Design based on the Design for Reliability: the reliability here is constructed consciously and actively into the design element during the design phase. The objetive of this approach is to achieve high accuracy in order to avoid "underdesign" and "overdesign". In the context of damage mechanisms expected due to the loads, the design element is created so that the stresses stay smaller than the strenghts during the service time, in accordance with the reliability requirements. The design is carried out through the optimal selection

of the system structure, the principle of the solution, design element geometry and arrangement, the material and the manifacturing process. It is possible to predict the reliability with the help of assessment concepts based on the computational interaction of stress and strength [12].

The practical use of DfR is:

- Identify systematically the reliability solutions and tasks during the design phase and the reliability-oriented design from the beginning;
- Prevent unplanned recursion during verification and validation;
- Reduce failure rates and costs and loss of reputation;
- Document and consolidate the product expertise and the manufacturing processes;
- Be able to transfer the expertise acquired with the design element to the next generation [12].

All approaches are applied on the products of Bosch, but the most important is number 5, Design based on DfR, since it is very important to understand the causes and consequences of the design for the products reliability.

3.4: Introduction to Weibull Analysis

Reliability Life Data analysis is referred as the study and modeling of products life behavior. With Life data analysis, also referred to as Weibull analysis, it is possible to make predictions about the life of the products by fitting a statistical distribution (model) to life data from a representative sample of units. The Weibull distribution can be used to estimate important life characteristics of the product such as reliability or probability of failure at a specific time, the mean time to failure (MTTF), the failure rate and $B_{X\%}$ Life [17].

Waloddi Weibull was a Swedish mathematician and engineer who invented the Weibull distribution in 1937 [16]. The Weibull distribution is widely used in reliability engineering, study of lifetime of products and to estimate equipment failures. This section provides a brief background on the Weibull distribution.

The 2-parameter Weibull distribution is the most widely used distribution for life data analysis and its probability density function (PDF) is given by [17]:

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

Where:

t = failure time

β = slope or shape parameter

η = scale parameter or characteristic life

The other reliability functions of the 2-parametric Weibull distribution are:

$$Reliability \ = R(t) = e^{-\left(\frac{t}{\eta}\right)^{\beta}}$$

$$Unreliability = Q(t) = \ 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}}$$

$$Failure\ rate = \lambda(t) = \frac{f(t)}{R(t)} = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1}$$

The failure rate is the number of failures per unit time that can be expected to occur for the product [17]. A failure rate that changes over the lifetime of the product population is classified into three phases: infant mortality, random and wear-out failures. The bathtub curve can be viewed as the sum of the three failure rates [13]:

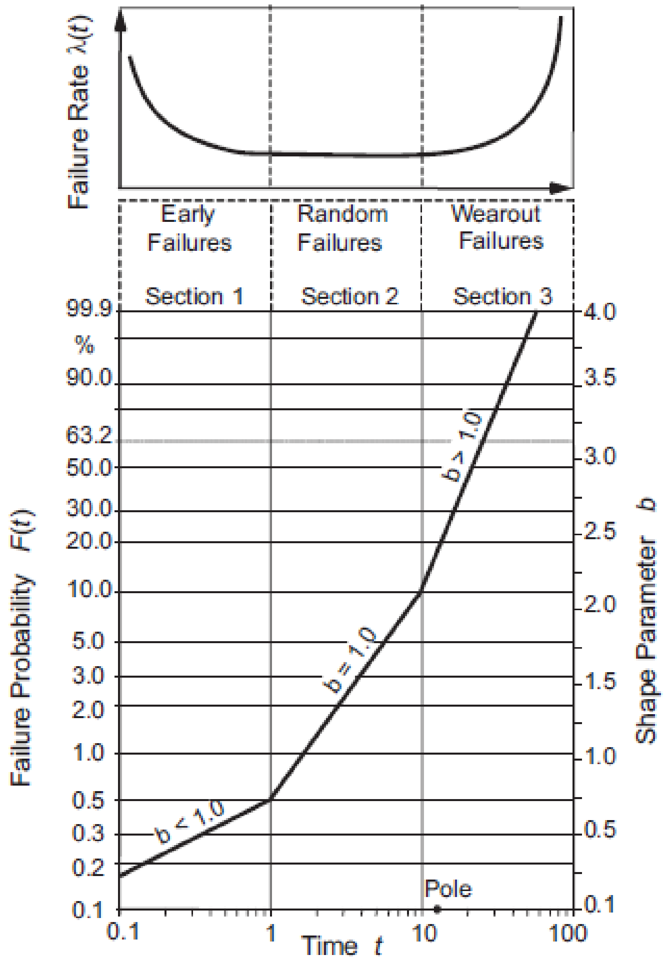

Figure 2: Bathtube curve. Each section is described with its own Weibull distribution and corresponding shape parameter β, represented by b, in the Weibull probability paper. [14]

The MTTF, mean time to failure, is an important reliability measure that is defined as the average failure time [16]. The relationship between η and MTTF is a gamma function of β (and is derived in Appendix G of [16]) is shown in the next equation for the 2-parameter Weibull:

$$\bar{T} = \eta \, . \, \Gamma\left(\frac{1}{\beta} + 1\right)$$

BX% Life is the estimated time at which X% of the products will have failed. For example, B10 is another reliability measure that indicates the time until 10% of the products fail, it means if 10% of the products are expected to fail by 100 hours of operation, then the B10 life is 100 hours [18].

The reasons to use the Weibull Analysis in Rexroth are:

- MTTF (Mean Time to Failure) calculation
- TCO (Total Cost of Ownership) calculation
- Life time prognosis
- Failure Forecasting and Prediction (reserve for outstanding losses)
- Warranty analysis and support costs prediction
- Risk management regarding the extension of the warranty period
- Identification of warranty fraud
- Calculation of needs regarding spare parts

3.5: Field Data evaluation

There are many different ways to visualize field data of products, which change from company to company according to their needs and products type.

There are different methods to visualize data and there is a variety of graph types to show different points of view of data evaluation. For example in the field testing of wood and wood-based products, concerning wood material deterioration, the following types of graphs were used to visualize the field test results [15]:

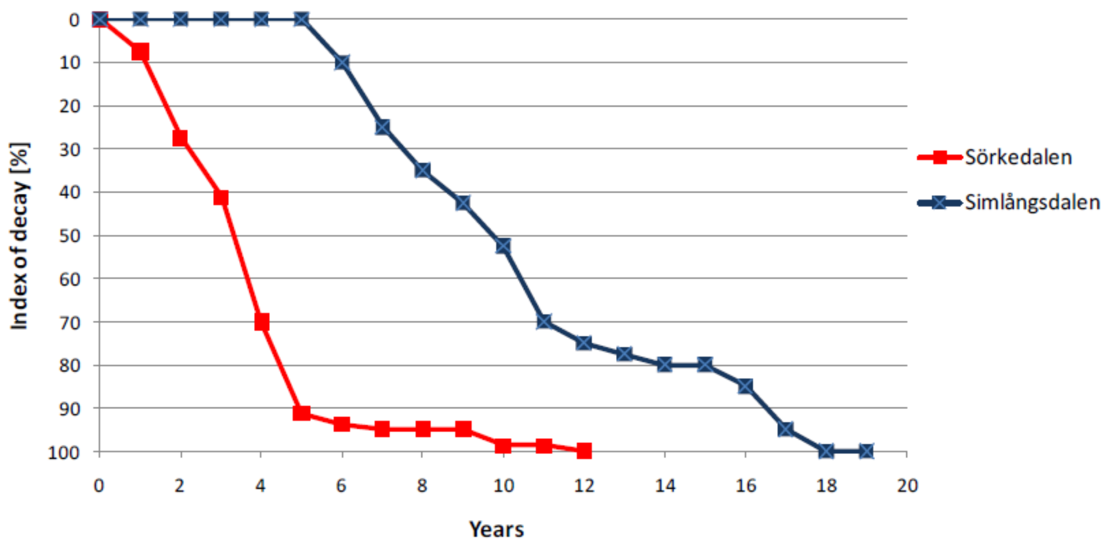

Figure 3: Stacked Line chart with markers.

Figure 3 shows a stacked line chart with an example of the index of decay plotted over time for pine sapwood stakes treated with a copper based preservative exposed in two different test fields [15].

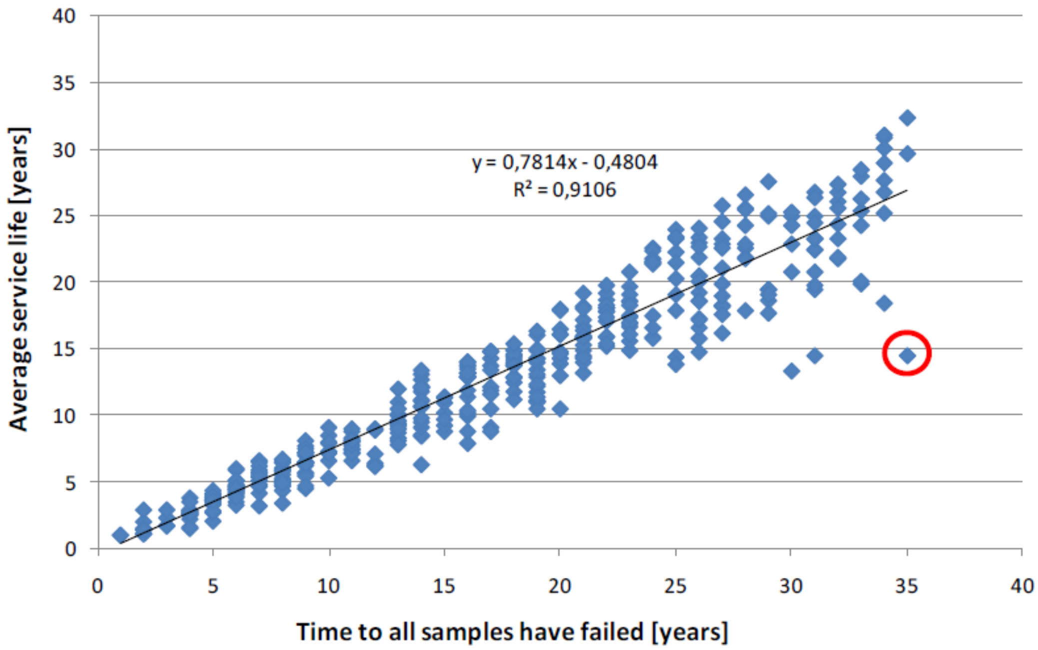

Figure 4: Scatter plot

The scatter plot in Figure 4 shows different Nordic field trials by plotting the average service life against the time until all samples within a group have failed [15].

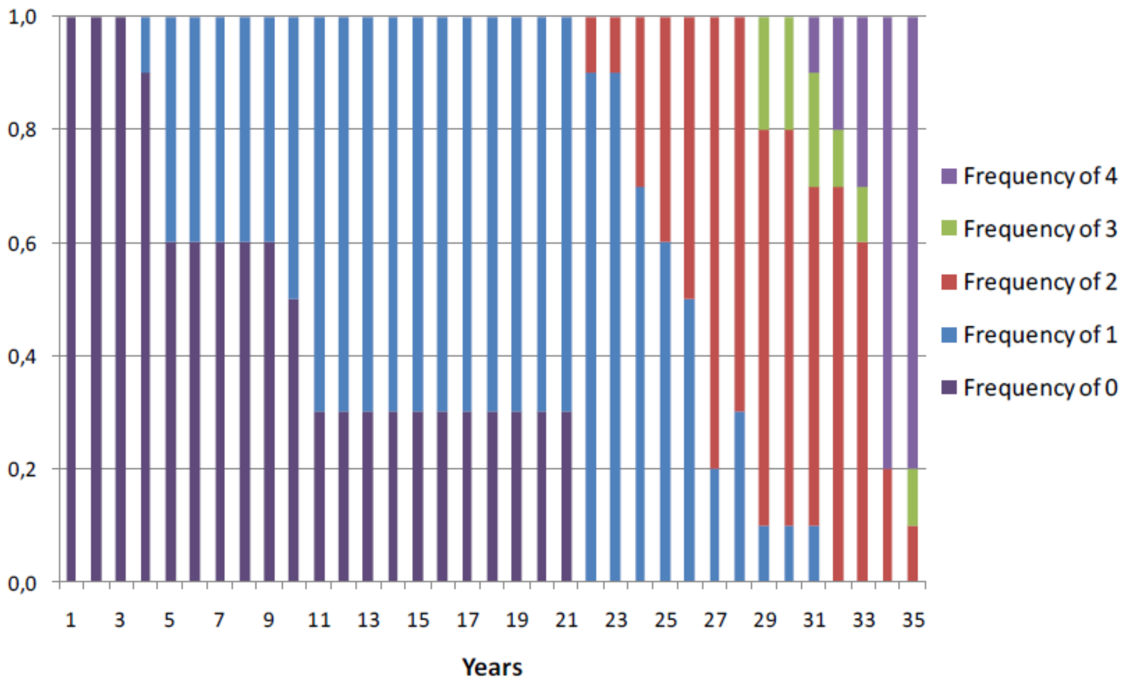

Figure 5: Stacked Column

Figure 5 show a stacked column graph with the frequency of ratings of decay over the years for pine stakes treated with a creosote type preservative [15].

There are a few challenges while evaluating field data, the uncertainties among the field data can be:

- Differentiation in end products or individual parts, spare parts, and assembly groups;
- Specification of operating hours (for example all customers have an average number of operating hours per year, but different products have different operating hours);
- Specification of the degree of coverage, which means the percentage of claimed units to actual number of failures;
- Specification of time offsets (for claim and delivery dates).

3.6: Quality tools for Root Cause Analysis

The classic seven quality tools for Root Cause Analysis are [22]:

- Flowchart → for graphically depicting a process. It can be used to map a process and thereby gain a better understanding of the factors relating to the process. A flowchart uses symbols to represent the flow of a process, including activities and decision points in a process.
- Pareto charts → for identifying the largest frequency in a set of data. The Pareto chart is based on the Pareto principle that estimates 80% of the effects are the results of 20% of the causes.
- Ishikawa diagrams (also called cause-and-effect diagram) → for graphically depicting causes related to an effect. It may not lead directly to a root cause, however, it could be effective in identifying potential factors for further investigation.
- Run charts → for displaying occurrences over time. Run charts are used for monitoring process performance over time to detect trends, patterns, shifts or cycles, it also allows a team to compare a performance measure before and after implementation of a solution.

- Check sheets → for totaling count data that can later be analysed. It can be used for multiple reasons, for example to collect data on types of defects, causes of defects, location of failures, etc.
- Scatter diagrams → for visualizing the relationships between variables. It can be used to look for patterns in the points that are plotted in the scatter plot, for exploring preliminary data or testing a hypothesis that there is a relationship between the variables.
- Histograms → for depicting the frequency of occurrences. It is used to graphically illustrate frequency distributions; a frequency distribution is the ordered rate of occurrence of a value in a data set.

The Quality tools for Root Cause Analysis can be used perhaps, for field data evaluation and failure visualization. The following figures show an example of each quality tool for Root Cause Analysis.

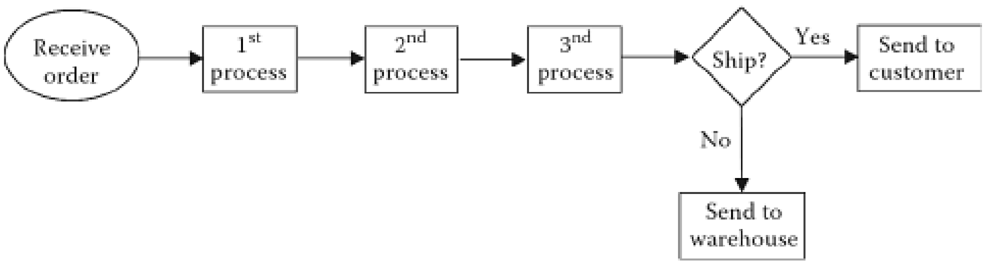

Figure 6: Flowchart

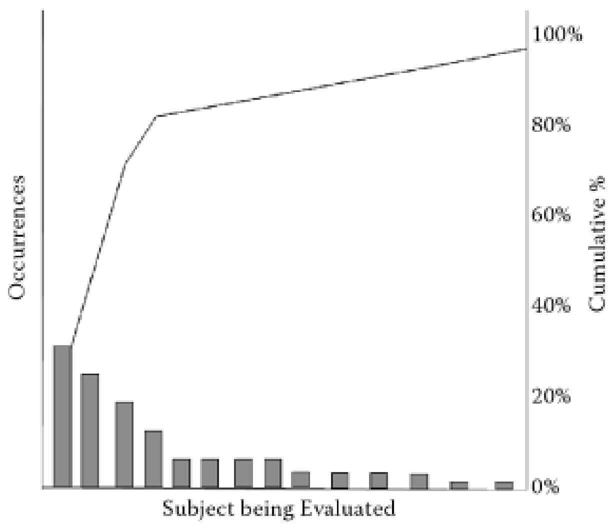

Figure 7: Pareto chart

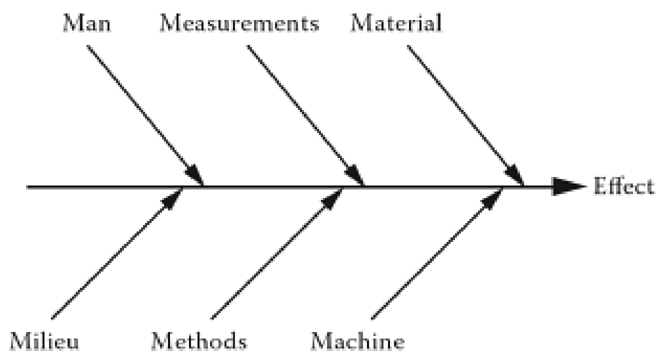

Figure 8: Ishikawa diagram

Figure 9: Run chart

Failure	**Number of Occurrences**	**Total**
Part missing	~~////~~ ~~////~~ //	12
Scratches	~~////~~ ~~////~~ ~~////~~ ~~////~~ /	21
Dimensional problem	~~////~~ ~~////~~	10
Wrong part	~~////~~ ~~////~~ /	11
Improper assembly	~~////~~ ///	8
Assembly problems	~~////~~ /	6
Total		68

Figure 10: Check sheet

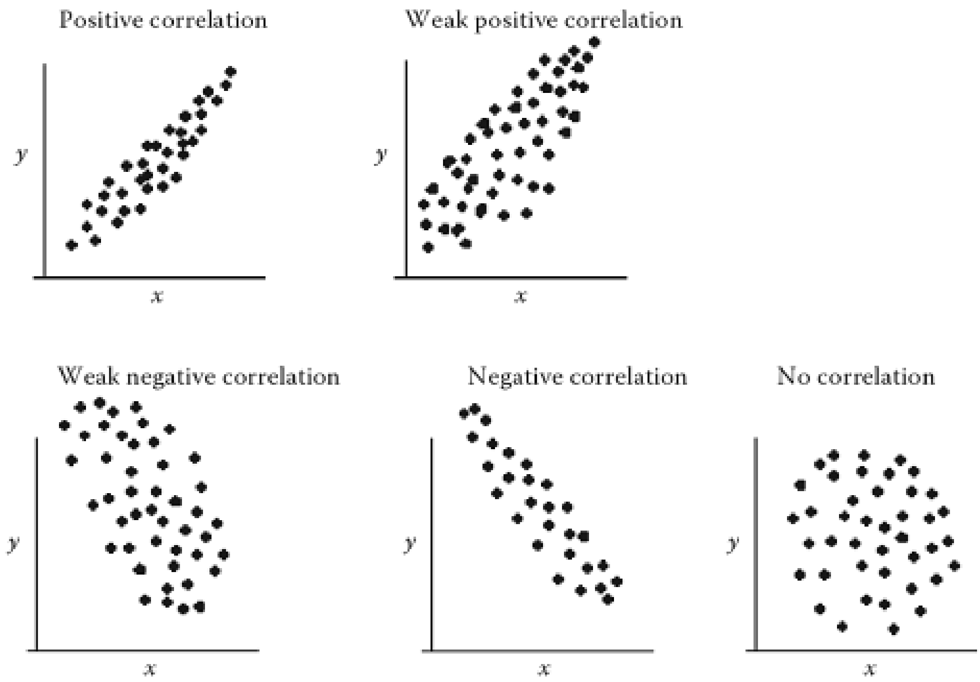

Figure 11: Scatter plot

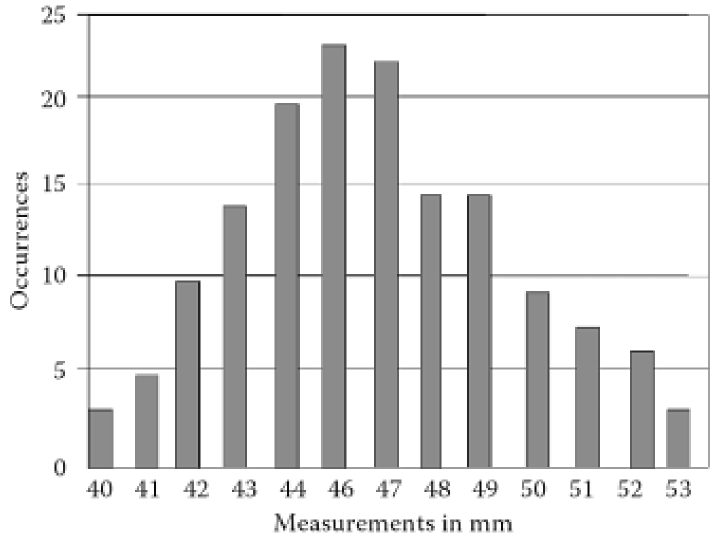

Figure 12: Histogram

Chapter 4: Concept of Reliability Evaluations

In this chapter, the problem description is explained and followed by the data visualization possibilities to evaluate the failures of equipment. In the end, the proposed solution is presented and aims to complete the concept of reliability evaluations realized in Bosch Rexroth.

4.1: Problem description

Bosch Rexroth has a huge database with detailed product information from the last 20 years. All this data, which contains information about deliveries and claims of products, can be used now to make field data analysis in order to get information about the products lifetime behavior. Due to field data analysis, important information about the products are retrieved and can be used to improve their quality and reliability. Currently, the delivery and claim data stored are used in reliability evaluations most through Weibull analysis.

With the Weibull analysis, the reliability measures MTTF and B_{10} can be calculated and other quality indicators can be analyzed as the curve shape and correlation coefficient. The failure prognosis are also estimated and in order to check if it has an acceptable result, a failure prognosis with data from the past is made and compared with the prognosis of real data, in other words, if the failure prognosis estimated based on the data from the past is close enough to the real data prognosis, the prediction is satisfactory.

In case the failure prognosis is not adequate, the specific problem must be sought. Normally in those cases, the Weibull distribution presents bad coefficients and the curve shape is not linear, and it usually means that mixed populations are evaluated together instead of being separately analyzed.

The Weibull analysis can be improved if better (filtered) data is used for the evaluation and consequently the failure prognosis as well. In this context, the visualization of failures is required so that the specific problems with the data can be found and the adequate data separated in order to get solid analysis results.

In the sequence, different possibilities of data visualization are presented with the intention of achieving the best data visualization of failures, where homogeneity of the population can be easily seen and selected as an input to Weibull analysis.

4.2: Data visualization types

There are many conventional ways to visualize data. However, choose the right way of data visualization can be a difficult task.

In a common scenario, you have a huge database and many questions to be answered. There are varieties of data visualization: tables, graphs, maps, diagrams, etc., that can provide useful meaning to see what lies within, find relations, determine the answer to a question, and perhaps show information which could not be seen so easily in other forms.

In the following sections, the possibilities of data visualization to implement in this project will be presented as part of the research phase of selecting the best charts to be used for the failure visualization of products.

4.2.1: Bar chart

Bar chart is one of the most common ways to visualize data, since it is easily used to compare information, showing highs and lows at a glance. Bar chart can be very useful with numerical data that splits into different categories [21].

It is also good to consider the colors of the bars to get more impact, use stacked bars or side-by-side bars, combine bar charts with other types of charts and put bars in both sides of the axis.

A simple bar chart can be used to show failure quantity for different product types over time period, as shown on the next figure:

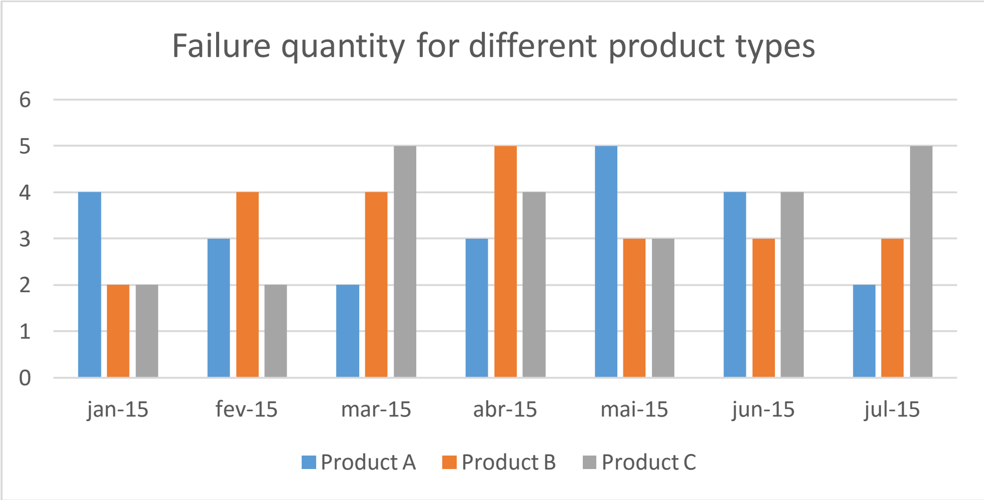

Figure 13: Bar chart example

4.2.2: Line chart

Line chart is also one of the most frequently used chart types. Line charts can be used to connect individual numeric data points to visualize a sequence of values. The most important use of line chart is to display trends in data over time [21].

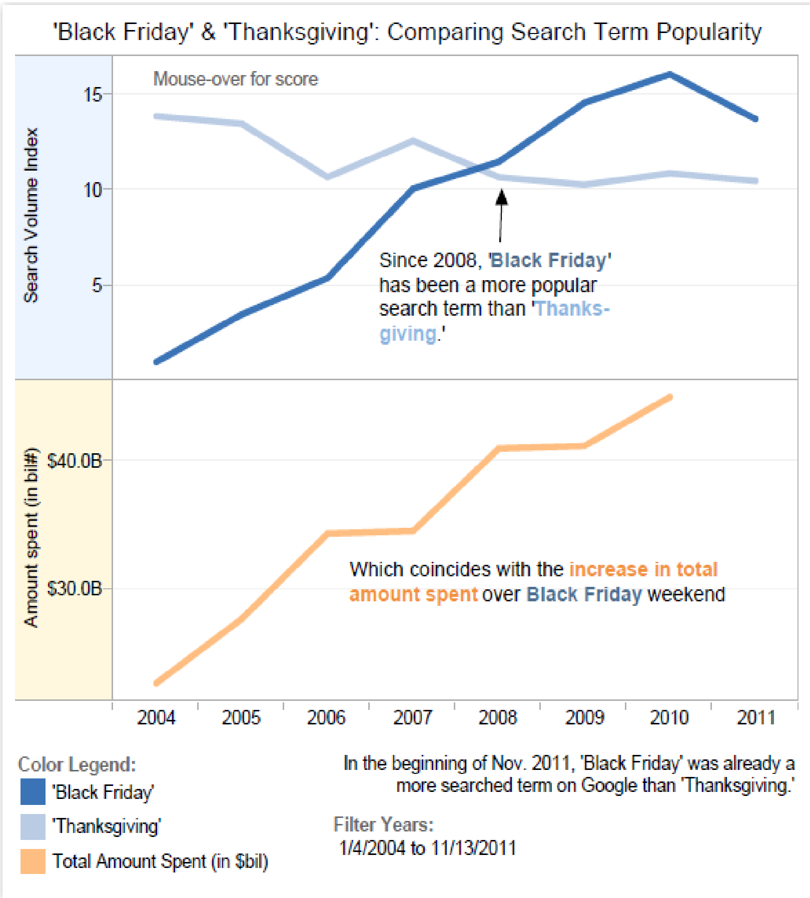

Figure 14: Example of Basic Line chart that reveal powerful insight [21]

One possibility to visualize trends between delivery and claim data can be represented by the combination of a line graph with a bar chart, with the line indicating the volume delivered per month while the bars correspond the amount of failures over time.

4.2.3: Pareto chart

Pareto chart is a bar diagram, where the length of the bars represent the values that are displayed arranged according to their size (the longest bars on the left and the shortest to the right). A Pareto chart is based on the assumption, that 80% of the effects are coming from 20% of the causes and tries therefore to display the critical parameters. In this manner the chart visually shows which situations are more significant [23].

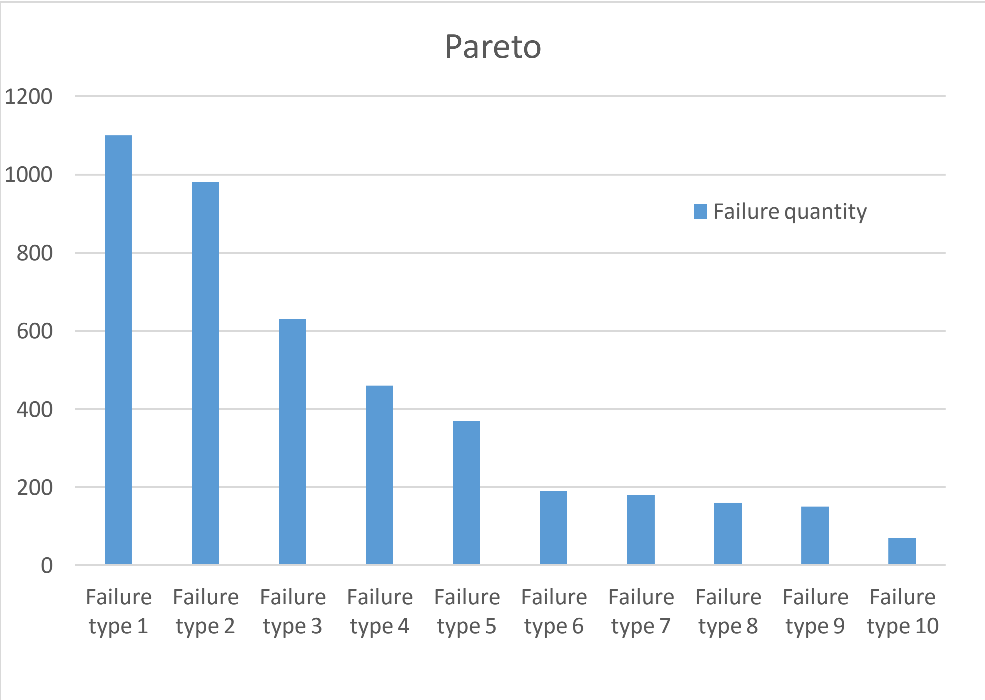

Figure 15: Pareto Chart Example

In quality control, Pareto charts often represent:

- the most common sources of defects,
- the highest occurring type of defect,
- the most frequent reasons for customer complaints.

Pareto chart is a good solution to visualize the failure causes of the products and see the most critical customers. Many Pareto charts can be created to visualize any category (critical customers, failure type, etc.); it is like looking at the same thing from different angles. Another possibility for the Pareto chart is using the costs of failures instead of quantity (see failures by costs).

4.2.4: Layer-line Diagram

Layer-line diagram, also called Isochrone chart, is a graph with many stacked lines. In quality management this diagram is usually used to display cumulative failures percentage according to production month and service time. The color of the lines represent the service time (the area under the lines can also be shaded), the Y axis has the cumulative percentage, and the X axis represents the production month [24].

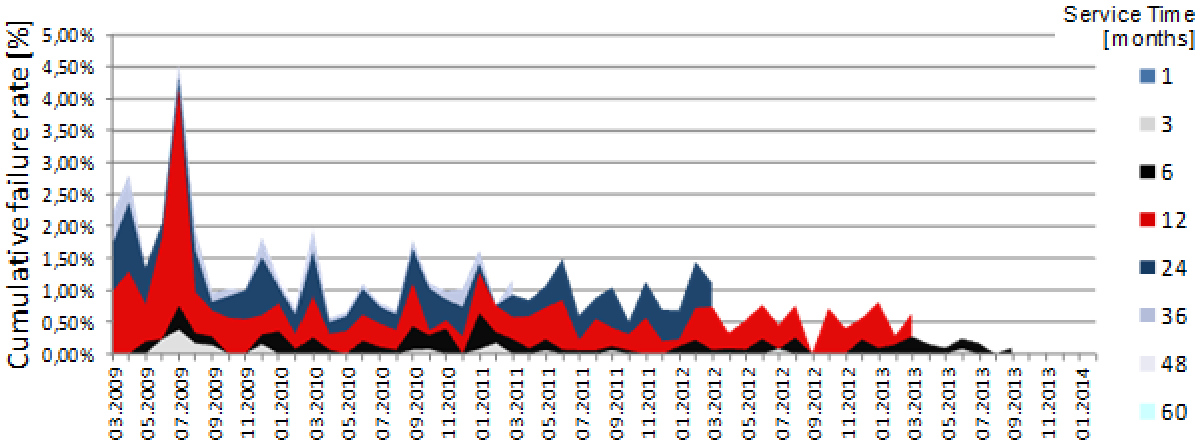

Figure 16: Example of Layer-line diagram

4.2.5: Scatter plot

A scatter plot is a graphical display of pair of values of two characteristics, whereby a cloud of points arises. Correlations can be identified through the pattern of the points and data groups can be distinguished 24].

Scatter plots are an effective way to give a sense of trends, concentrations and outliers. It is a good option to investigate the relationship between different variables [21].

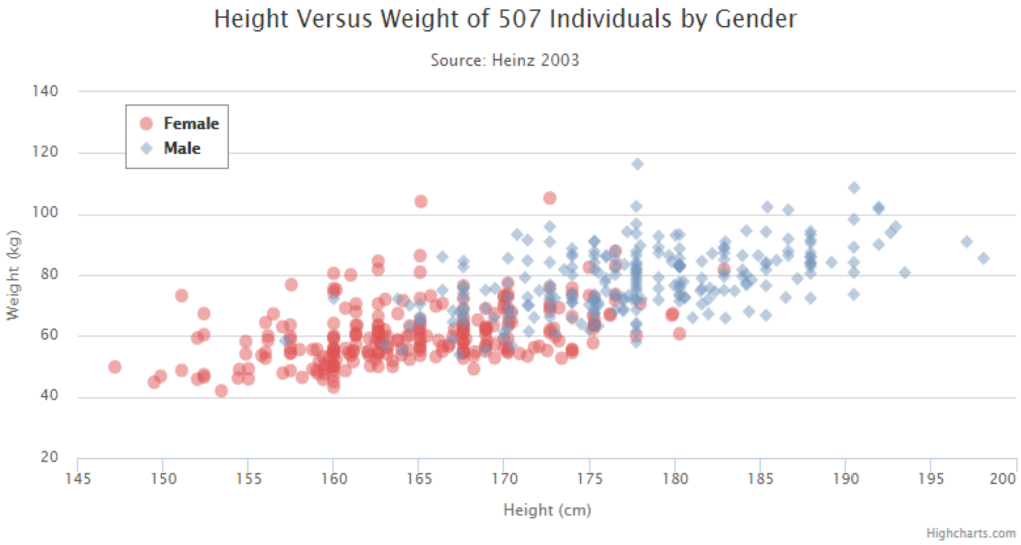

Figure 17: Scatter plot example

4.2.6: Bubble Graph

Bubbles are a technique to accentuate data on scatter plots. Using bubbles it is possible to vary the size of circles providing meaning about the data. When bubbles differ by color as well as size the impact is intensified [21].

Bubble charts are useful for comparing the relationships between data in 3 dimensions: the X-axis data, the Y-axis data, and data represented by the bubble size. It is a good solution to show the concentration of data along two axes.

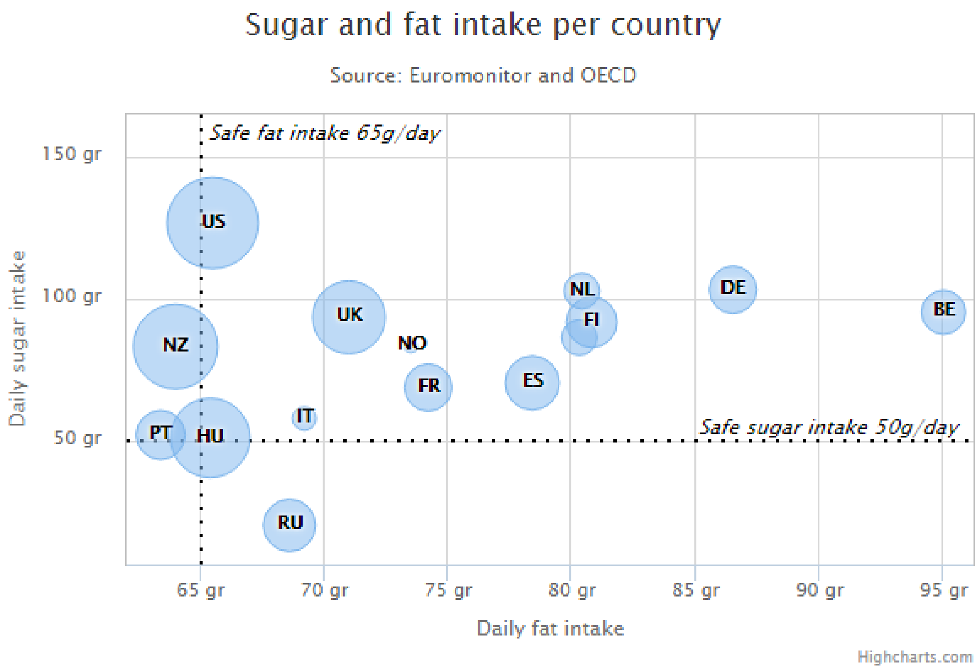

Figure 18: Bubble chart example

The bubble chart can be usefull to show the failure quantity concentration, for example for different customers, over a time period.

4.2.7: Pie Chart

Pie chart can also be another possibility to visualize the data. Pie charts show the relative proportions (percentages) of information. It could be used to show the percentage of failure types, or claims by customer, or material, etc.

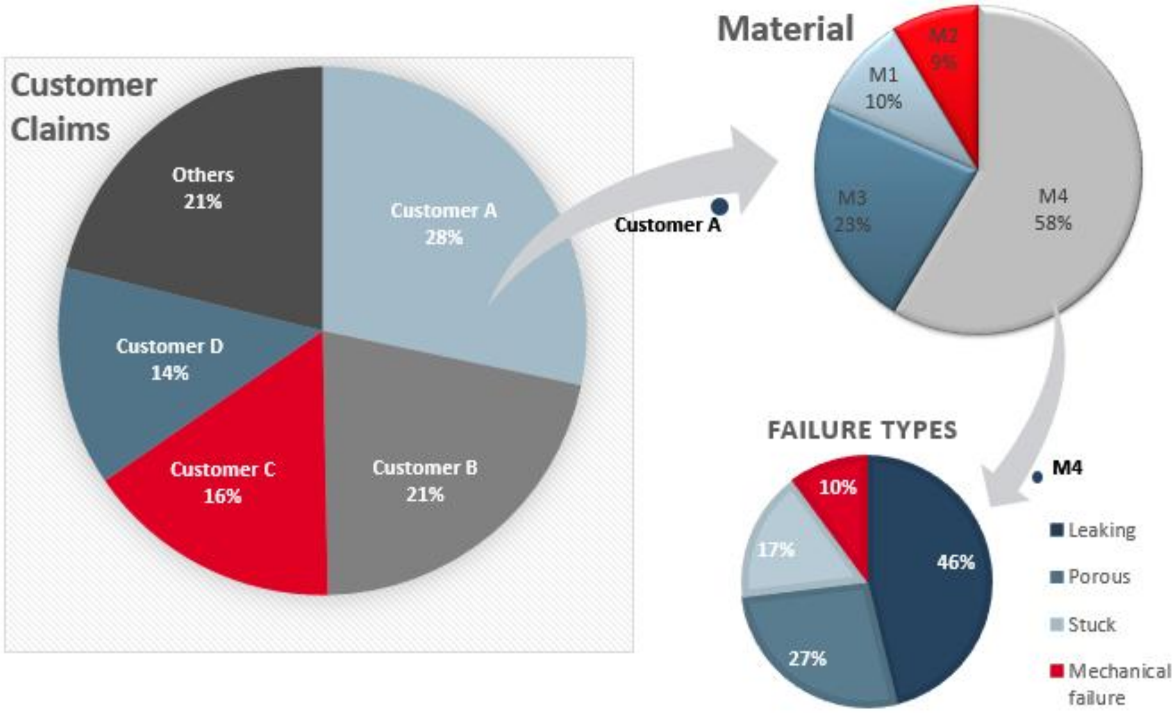

Figure 19: Pie chart examples

4.3: Interface to Weibull evaluations

The selection of the right charts to visualize the failures is an essential step that will guide the filtering of the dataset that will be used as an input to the Weibull analysis mentioned before.

The main reason to create a Weibull analysis is to estimate the reliability of a product in a specific application or environment. The results are used not only to estimate reliability, but also the adequacy of a design, and for developing maintenance advice. Filtering the information is very important to separate the data in order to get accurate results. This requires identifying the reason why there are different failures in the dataset, which could be [25]:

- more than one reason for the product failures,
- the same reason for failure, but the products are in different operating environments,
- the same reason for failure, but the products have different part manufacturers or production lines,
- closely grouped set of serial numbers, indicating a bad production lot,
- same type of failures but different reasons.

In sum, failure visualization over time, made with the adequate charts selection, is required for filtering data (and/or filtering the right time period) that will be used as input for multiple Weibull evaluations. The multicurves of Weibull with specific information will result in better reliability measures considering each specific application, instead of one Weibull curve with bad indicators on account of mixed information.

4.4: Proposed solution

As a solution for the failures visualization and evaluation, a field data analysis tool was decided to be created with the following charts combination:

- ✓ One graph containing Line and Bar charts → the line graph will have the delivered quantities of the products, while the bars will show the claimed quantities. The information will be displayed over a time period, so that the user can have an idea of the relationship between the delivery and claim quantities.
- ✓ Isochrone chart → the colors of the lines will represent the service time and the area under each line will be shaded (creating an area chart). The Y-axis will show the cumulative percentage of failures while the X-axis will represent the production months.
- ✓ Bubble charts → the Y-axis will contain the type of information selected by the user (it can be customer name, failure type for example), the X-axis will show the production time, or service time, or failure time, in months. The bubbles will be displayed in a line for each information on the Y-axis and their size will represent the failure concentration in each time period.

A filter selection will be possible among the bubble charts. It will be possible with the way the failures are displayed over time to see the failure concentration for each product family, failure location, failure type, the critical customers, etc. With the bubbles, it will also be possible to identify the homogeneity of the population being evaluated, and/or see time period when bigger amount of failures occur, or even recognize patterns on the data.

The data selected during the bubble analysis can be then used as an input for a further Weibull analysis, which will show better reliability measures and consequently better failure prognosis for each specific application.

The Pareto chart would also be a good solution to visualize the root cause of failures, but the data visualized has no time information.

The pie charts also have no time information, but can be implemented in the future with the bubble charts to show the proportions of the information selected by the user in a more interactive way, as was shown previously on the example of figure 9.

Chapter 5: Tool Implementation

This chapter describes the Field Data Analysis process, its implementation in a software tool and summarizes the process of the software development.

5.1: Field Data Analysis process

The Field Data Analysis Tool developed for this project and its integration with the Weibull Tool in one program in Python, intends to make the analysis of failures for Bosch Rexroth easier and faster. The analysis of failures that is currently done can be described by the following main steps:

1. Claim and Delivery data are collected from the SAP database.
2. The Claim and Delivery data are manipulated in MS Excel.
3. Data input is done manually into Weibull++ software (commercial software from ReliaSoft) through copy and paste of cells.
4. The analysis of failures is made using Weibull++ software and in case of the failure model acquired is unsatisfactory, then the process returns to the step number 2.
5. Calculation of failure forecast is in Weibull++.

The use of two different softwares and absence of some desired functionalities makes the failure analysis evaluations time consuming and difficult.

The in-house developed software makes the Weibull analysis and the field data evaluations possible in one single program; it allows the filtering, the execution of steps 4 and 5 and eliminates the step 3. The analysis process can be faster and easier with the new program.

5.2: Input data

The SAP/R3 is the standard Enterprise Resource Planning (ERP) software implemented nowadays in most of the Bosch Rexroth units around the world. Its use include collect, store and manage product data, besides many other functionalities.

The Claim and Delivery data, which come from a SAP database that has been collected for more than 20 years by Bosch Rexroth, have several information about the products.

The information from SAP (or any other database used in Bosch Rexroth units) can be retrieved as Excel tables and the acquired files are very much alike to the ones shown on the next figures:

Delivery date	Customer	Quantity	Material Description	Delivery Number	Production Plant	OEM	...
01.01.2002	AAAA	25	MD_1	11234456	Lohr	XXXX	...
01.01.2002	BBBB	25	MD_1	11234457	Lohr	XXXX	...
01.01.2002	BBBB	25	MD_2	11234458	Lohr	XXXX	...
01.01.2002	CCCC	25	MD_1	11234459	Pomerode	XXXX	...
01.01.2002	AAAA	25	MD_3	11233445	Pomerode	YYYY	...
01.01.2002	DDDD	25	MD_3	22587741	Pomerode	YYYY	...
01.01.2002	EEEE	20	MD_4	22587743	Lohr	YYYY	...
01.01.2002	AAAA	18	MD_2	22587744	Lohr	ZZZZ	...
01.01.2002	CCCC	17	MD_5	22587745	Atibaia	ZZZZ	...
01.01.2002	HHHH	16	MD_5	22587746	Atibaia	XXXX	...
01.01.2002	HHHH	15	MD_1	22587748	Atibaia	XXXX	...
01.01.2002	FFFF	14	MD_2	18455623	Lohr	ZZZZ	...
01.01.2002	GGGG	16	MD_2	32556641	Pomerode	TTTT	...
01.01.2002	BBBB	14	MD_6	12345665	Atibaia	TTTT	...
...	...	...	...	...	...		...

Figure 20: Example of Delivery data

Complaint date	Complaint number	Delivery date	Final Customer	Quantity	Failure Type	Failure Part	Production Plant	OEM	...
01.06.2009	123456	01.01.2002	CCCC	1	211	11234456	Lohr	XXXX	...
01.04.2006	123457	01.01.2002	HHHH	1	111	11234457	Lohr	YYYY	...
01.12.2010	123458	01.01.2002	HHHH	3	111	11234458	Lohr	TTTT	...
01.06.2008	123459	01.01.2002	FFFF	1	122	11234459	Pomerode	XXXX	...
01.06.2011	123478	01.01.2002	GGGG	2	123	11233445	Pomerode	ZZZZ	...
01.04.2010	125469	01.01.2002	BBBB	1	332	22587741	Pomerode	ZZZZ	...
01.04.2012	125465	01.01.2002	DDDD	1	112	22587743	Lohr	TTTT	...
01.08.2009	136452	01.01.2002	FFFF	3	141	22587744	Lohr	XXXX	...
01.09.2012	136458	01.01.2002	AAAA	1	121	22587745	Atibaia	YYYY	...
01.10.2010	325468	01.01.2002	BBBB	1	111	22587746	Atibaia	YYYY	...
01.05.2010	698545	01.01.2002	BBBB	5	122	22587748	Atibaia	TTTT	...
...	...	...	...	...	...	...	...		...

Figure 21: Example of Claim data

The delivery data contains the date when the products were delivered, the quantity sold, type of product, Original Equipment Manufacturer (OEM), customer, and other information. The claim data has the failures quantity recorded, claim and delivery dates of the products, product name, serial number, product family, OEM, end customer, failure description, failure location, etc.

Unfortunately, data inconsistencies occur frequently, especially when it comes to standardization and maintainability of fields, which means that not all fields are completed correctly, and sometimes there is no standard to record the data (and the data presents different names on the delivery and claim tables, for example).

Due to data inconsistencies, the tables must be manipulated before to be used as input data on the software tool, in order to get satisfactory results, i.e., it should have same customer names, codes, family products names, country names, OEM, etc., in both claim and delivery tables (written in the same way, so that the claimed and delivered quantities can be correctly compared).

5.3: Software Development

The development process of the Field Data Analysis tool was carried out in 3 phases that are summarized in the following sections.

5.3.1: Program Functionalities

The program functionalities were specified together with Bosch Rexroth reliability and quality engineers. Due to the specific needs, the following functionalities were selected:

- Visualization of information in three different graphs:
  - One Bar + line chart
  - One Isochrone chart
  - Possibility of 60 Bubble chart
- Zoom time, described as the period selection (time filter).
- Zoom specific information of the Y axis of bubble charts, using check boxes to select the information displayed on the graph (field data filtering).
- Parallel display of Claim data with Delivery data on the bubble charts.
- Display the specific Claimed and Delivered quantity shown on the bubble chart in comparison with the whole data.
- Be able to choose the number of characters of the information selected to be displayed on the bubble chart, and gather the delivered and claimed quantities for the names in the same group.
- Export functionality.
- Filtered data as an input for Weibull analysis.

5.3.2: Architecture Design

The software architecture is based on the Model-View-Controller (MVC) pattern. The MVC divides an interactive application into three components. According to Gries, Campbell & Montojo, 2013 [20]: “the model is the data being manipulated; the view displays the current state of the data and gathers input from the user, while the controller decides what to do next”. View and controller together compose the user interface, while the model contains the core functionality and data [19].

The MVC allows the segmentation of the complexity of programing a graphical user interface in a structured way. It facilitates the development and also allows code reuse and easier future changes.

5.3.3: Programming Language

The programming language used to develop the software was Python for being an open source language free of charge.

The list of Python 2.7 non standard libraries used, with the description of its usage in this project and the license regent which rules its use and distribution are shown in the next table:

Python Library	Usage	License Regent
Matplotlib	2D Plotting	PSF
Pandas	Data analysis	BSD
openpyxl	Read/write MS Excel files	MIT
xlwings	Read/write MS Excel files	BSD
Numpy	Scientific Computing	BSD
SciPy	Scientific Computing	BSD
SymPy	Symbolic mathematics	BSD

PSF = Python Software Foundation

BSD = Berkeley Sotware Distribution

MIT = Massachusetts Istitute of Technology

Chapter 6: Tool Results

After the whole process of defining the types of data visualization and its implementation in a software tool integrated with Weibull evaluations, the results acquired for the field data analysis are presented on the sequence.

6.1: User Interface

The graphic user interface was implemented with the Tkinter module (“Tk interface”), the standard Python interface to the Tk GUI toolkit.

When the program is started, the first window displayed is seen in the next figure. The area 1 has the field to load the appropriate excel tables containing the delivery and claim data to be analysed. After the tables are loaded, the user choose in area 2 the delivery data (delivery date and quantity delivered) from the table of delivery, and in area 3, the user choose the claim data (delivery date, quantity of claims and claim date) from the table of claim.

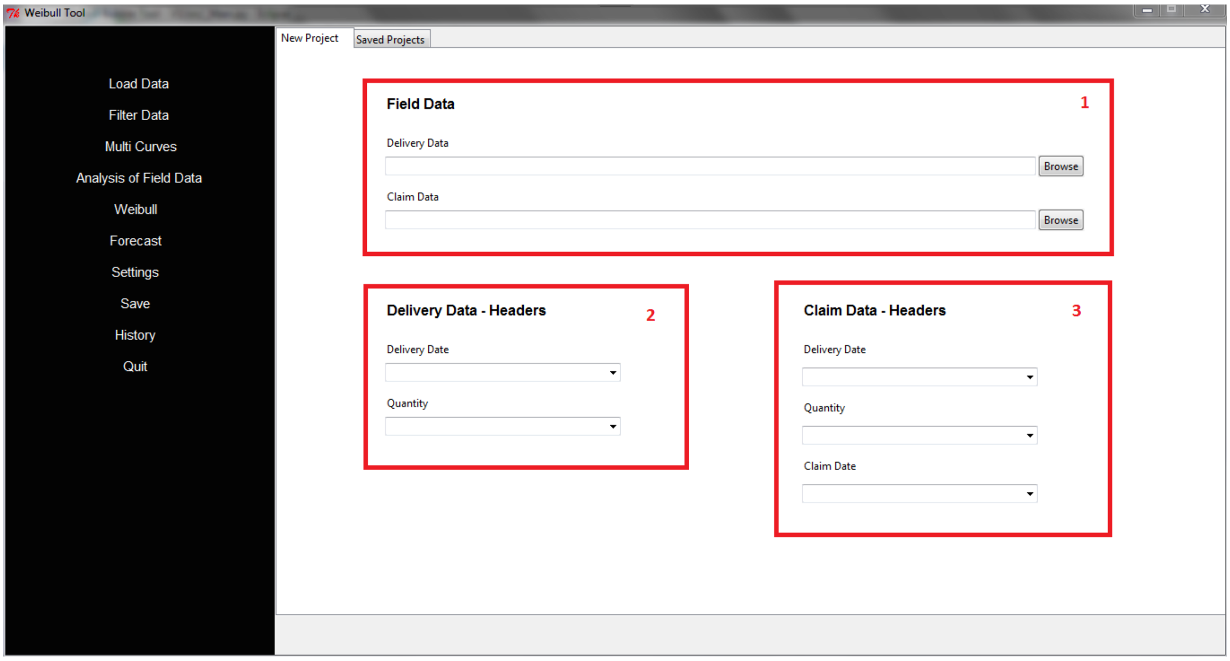

Figure 22: New Project selection

After the data selection, the user can start to use the tool functionalities. Figure 12 shows the Settings window for the field data analysis. In this window, the user can select in area 1, the time period to be evaluated (if no date is selected, the evaluation will be made with the whole data, i.e., with no time filtering). In area 2, the user has the option to visualize the delivered quantities in the bubble charts in comparison with the failure quantities, selecting the check box to enable the columns with the delivery data placed in area 3. In area 3, the user has the possibility to select 20 different kinds of information to be visualized on the bubble analysis.

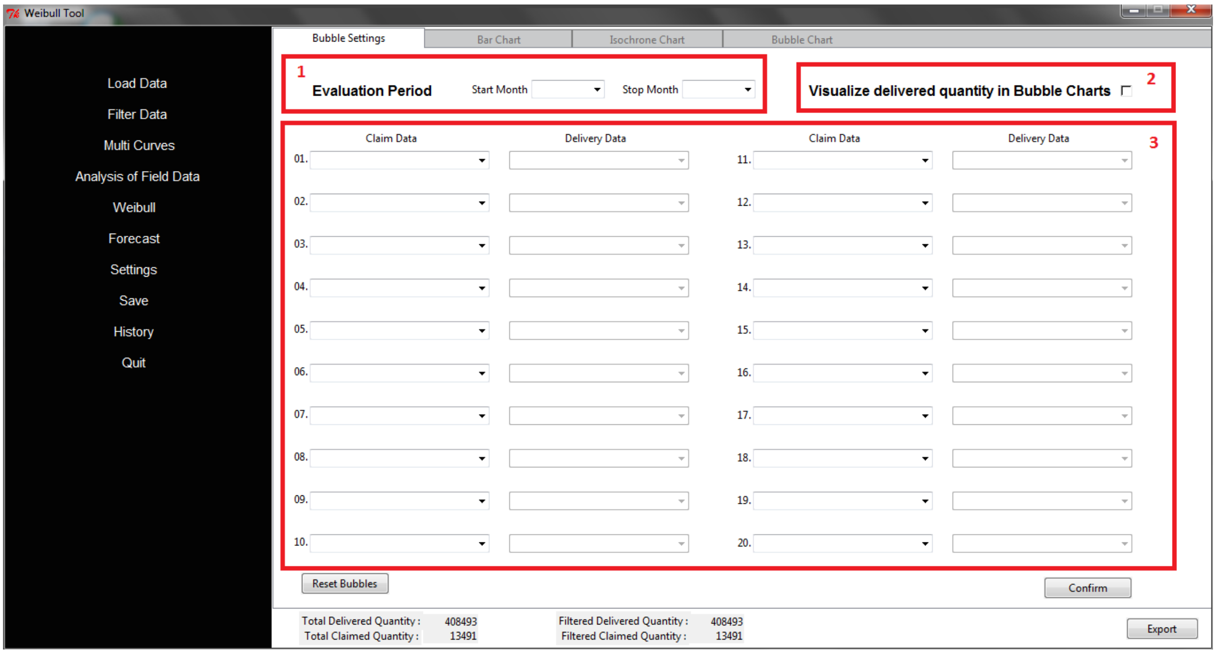

Figure 23: Bubble Settings

When the user is ready with the data selection and press the confirm button on the bottom of the settings window, the bar chart and isochrone chart will be generated, in addition with three bubble charts for each kind of information chosen on the settings. Each information selected will generate one bubble chart showing the failures with the production time, another with the service time, and the last one with the failure time, that is to say if the user selects 20 possibilities of bubble analysis, 60 bubble graphs will be created together with one bar chart and one isochrone chart. The bar chart and the isochrone chart can be seen clicking on the tabs on the top of the window, while the bubble charts can be visualized clicking on the buttons created (after the information selection and confirm button is pressed) on the right side. All the buttons for the bubble charts are placed on the right side of the screen so that the user can reach the graphs with only one click.

On the bottom of the screen, the delivered and claimed quantities can be compared in three different categories: Total (which contains the whole data quantities from the loaded tables), Filtered (if case the data is previously filtered in the Filter Data option shown on the left side of the screen) and Bubble (after the bubble data is selected and confirmed).

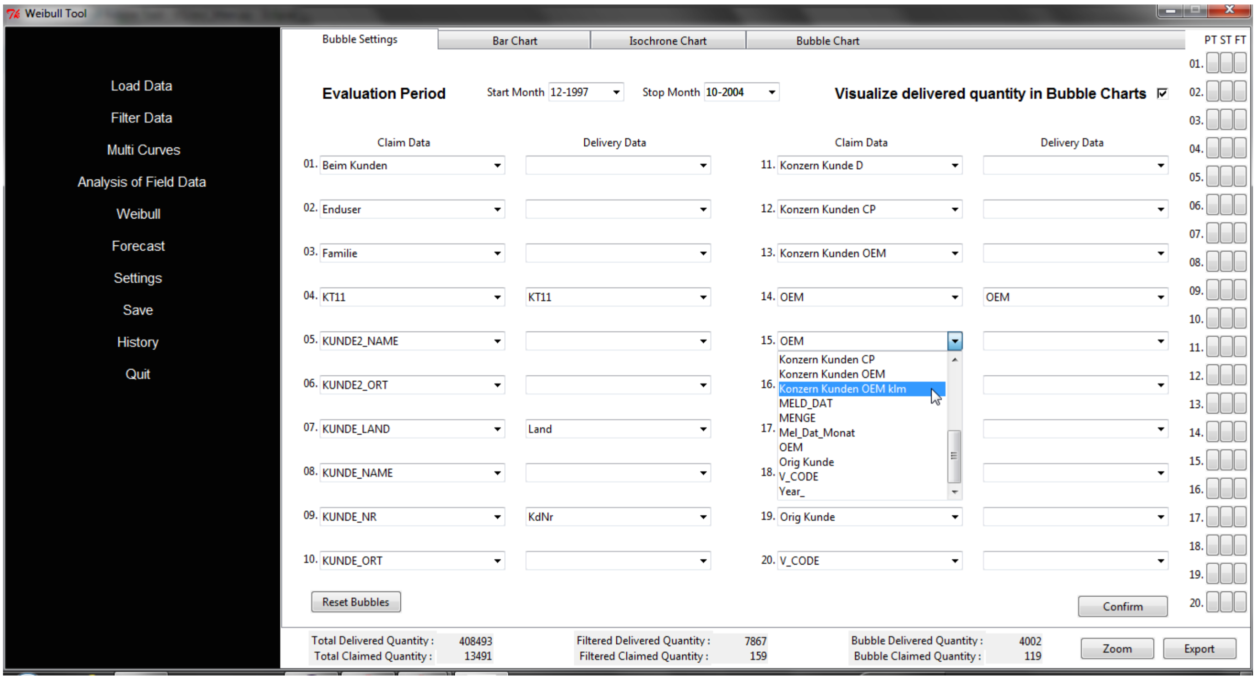

Figure 24: Settings selection and buttons

After all graphs have been generated, the user has the option to export them all to an excel file, clicking on the Export button on the bottom of the right side of the tool.

6.2: Bar and line chart combination

The bar and line chart show the relationship between the delivered and claimed quantities over a time period. The line graph has the produced units information while the bars represent the failed units. With this chart combination, it is possible to get a sense of how the business is doing. On the next figure, the result of these charts combination shows that during the years of crisis the produced units decreased considerably, for example.

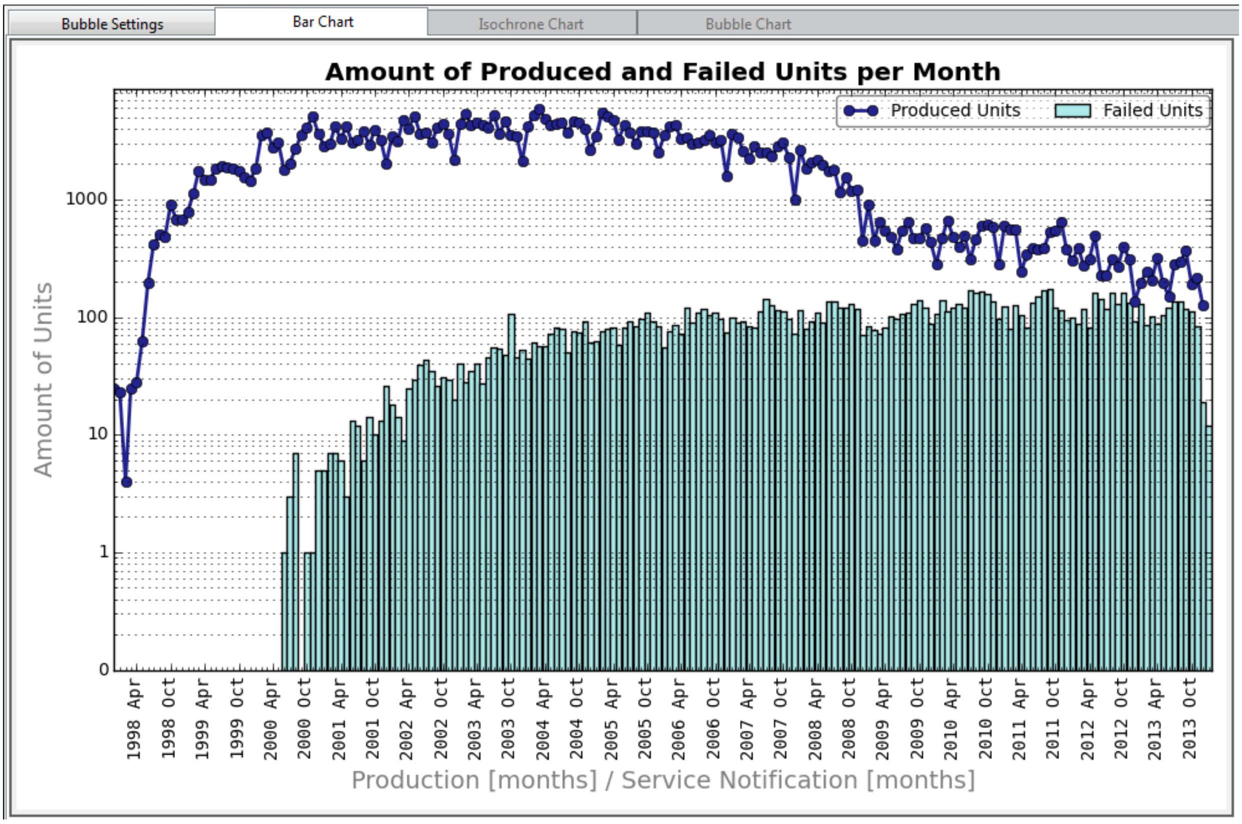

Figure 25: Bar and line chart combination

6.3: Isochrone Chart

The isochrone chart shows the cumulative percentage of the products failures on the Y axis and the production month on the X axis, while the color of the areas represent the service time. With this chart it is possible to easily compare the cumulative failure for each production month, also analyze early failures and visualize if the problems during the first months of production were fixed later.

The following chart was created in excel, but it will be future implemented on the field data analysis tool.

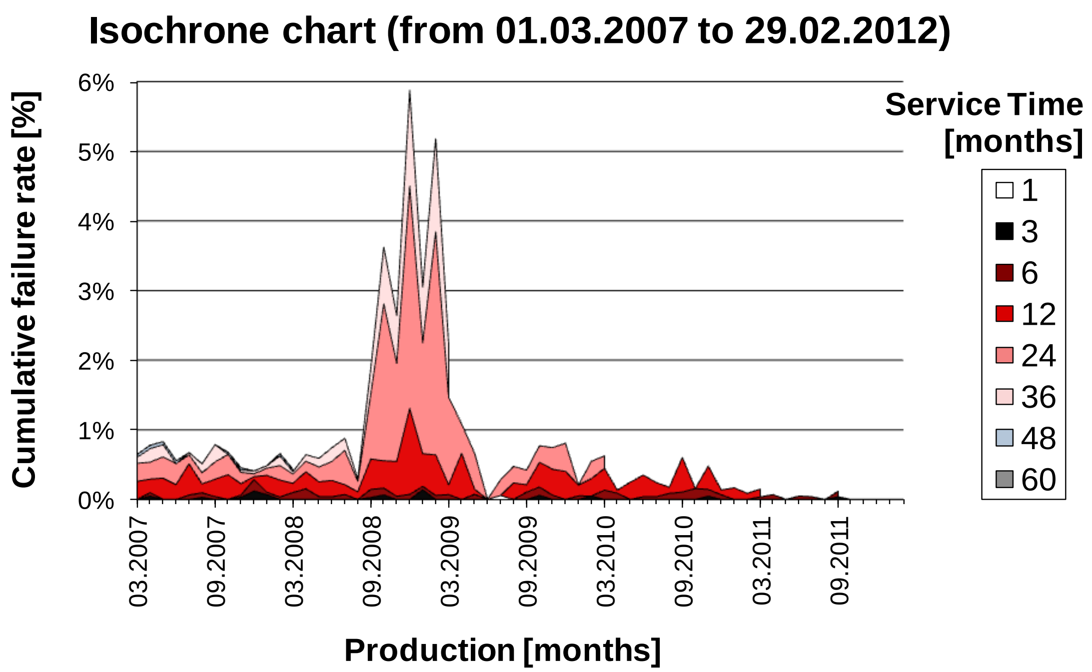

Figure 26: Isochrone chart example

6.4: Bubble Charts

The bubble chart was the best way selected for the field data analysis to visualize failures over a time period. With this chart it is possible to recognize among the failure concentration, patterns on the data, moreover, the failure distribution can show the homogeneity of the population and help to identify critical failure problems.

The user has the possibility to make bubble analysis of customers, products, failure types, failure locations, warranty decisions, etc.

When the Bubble Chart tab on the top part of the tool is selected, it only guides the user to click on the buttons on the right side in order to select the bubble chart the user wants to visualize. The numbers by the buttons represent the order of the charts disposal according to the selections made on the bubble settings, shown previously in figure 24.

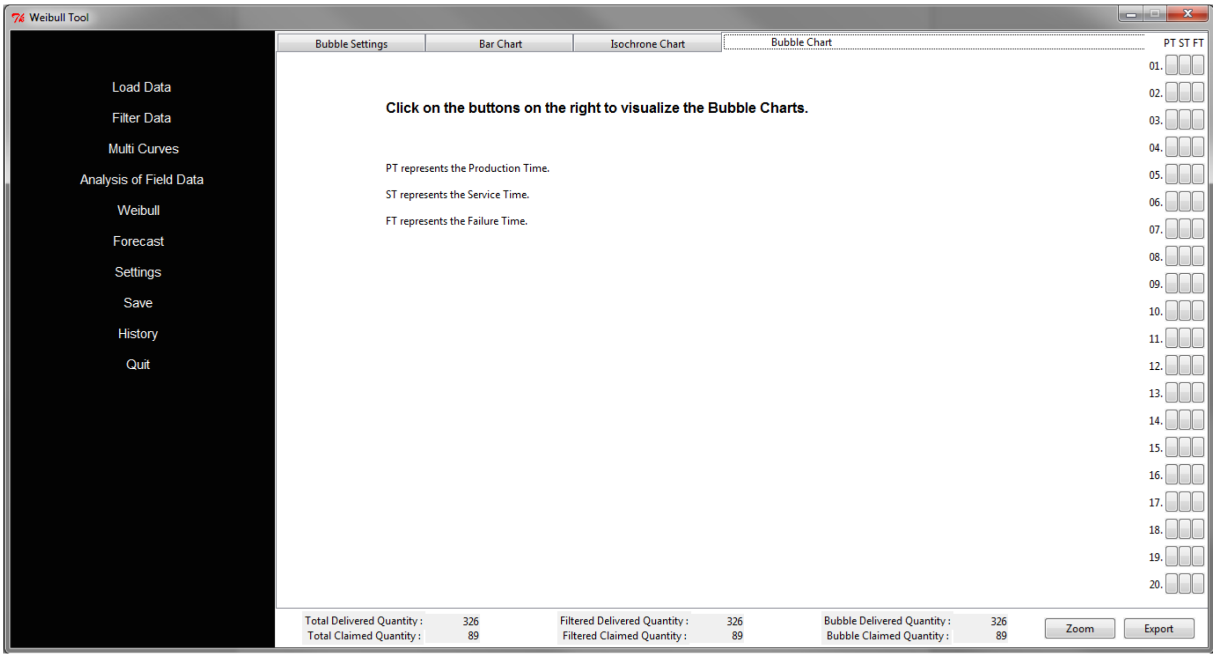

Figure 27: Bubble Chart tab

The bubble chart results using fake data for tests are shown on the sequence as an example for the bubble analysis. On the bottom of each chart, the user can see the relationship between the quantities shown within the Top 15 critical groups of data. For the following bubble examples, the delivery data was selected on the bubble settings menu so that the delivered quantity can be compared (on the right side of the chart) in regard to the failures amount (on the left side of the chart). Each group of data has its own color for the bubbles, which are disposed in a horizontal line sequence throughout the time period.

6.4.1: Bubble chart with Production Time

The bubble chart with the production time can show abnormal failure concentrations, that can maybe indicate a bad production lot for example. On the following example, the OEM 51 has a big failure concentration on June of 1999, that can be further analised filtering the data in order to seek where the problem is, comparing other information as material, family, failure type, customer, etc.

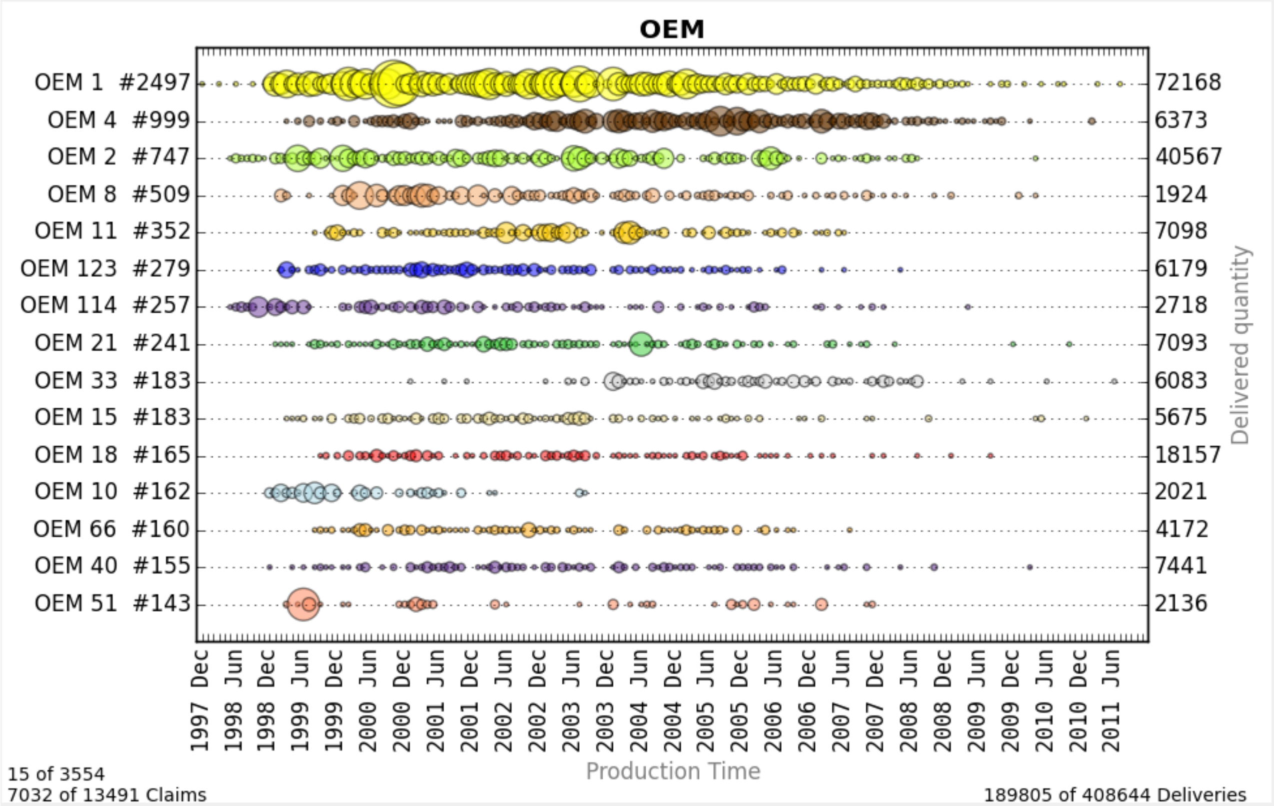

Figure 28: Bubble chart example with Production time

The main reasons to analyse the failures with the bubble charts containing the production time information are:

- ✓ Detect process issues
- ✓ Identify design problems
- ✓ Recognize supplier issues (as new materials, components or subsystems)
- ✓ Check how good improvement process is working
- ✓ Detect environment issues on the plants

6.4.2: Bubble chart with Service Time

The bubble chart with the service time is a good solution to visualize the homogeneity of the population for an specific application. The service time is the time between product delivery and claim dates.

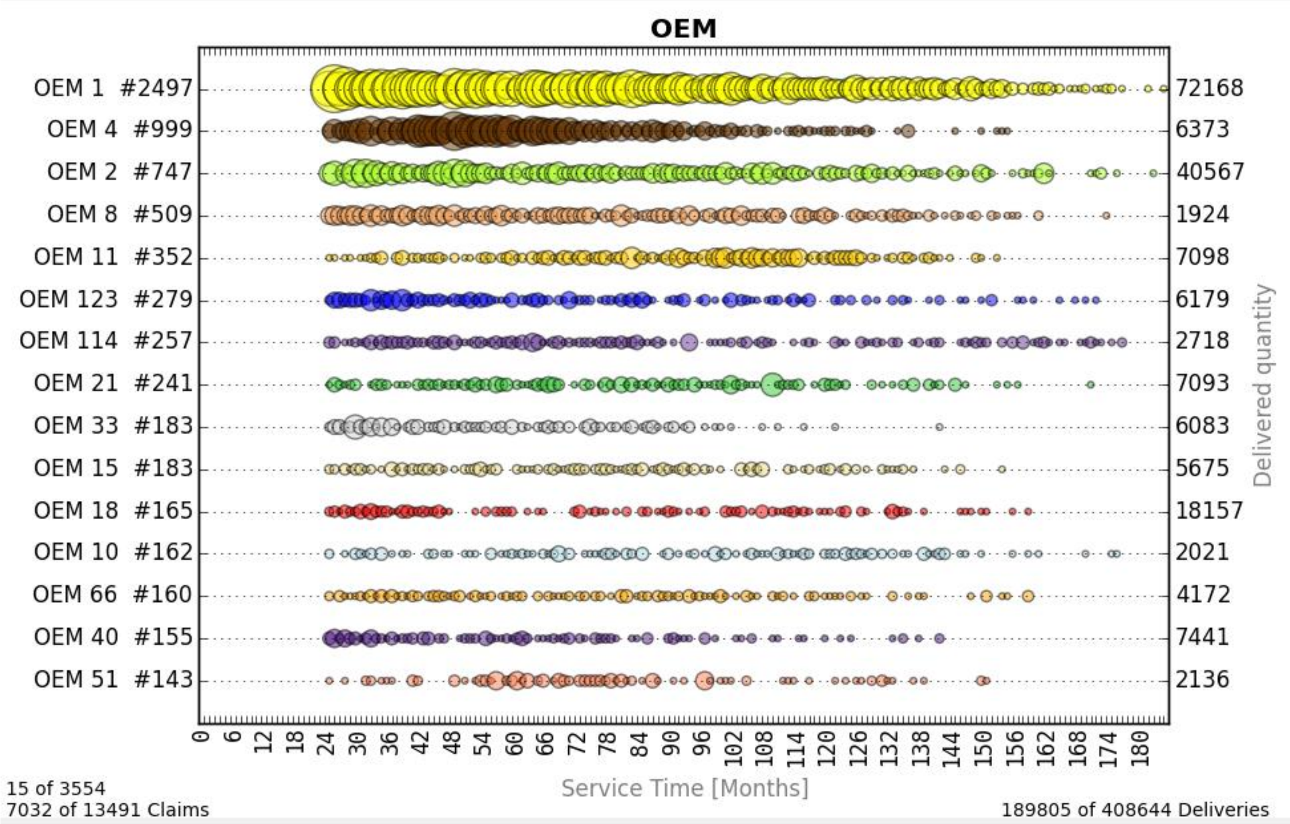

Figure 29:Bubble chart for example with Service time

The bubble charts with the service time information are useful to recognize:

- ✓ Different applications problems
- ✓ Problems with the customer regarding installation
- ✓ Claiming behavior (identify if customers are complaining after warranty period)
- ✓ Identification of zero hours complaim
- ✓ Data problems or data quality issues, regarding delivery or manufacturing date

6.4.3: Bubble chart with Failure Time

The bubble chart with the Failure time is useful to identify patterns and trends of the data. For example, it is possible to see the months of the year when the biggest failure concentrations occured, indicating possibly that some products are more likely to failure during some season of the year.

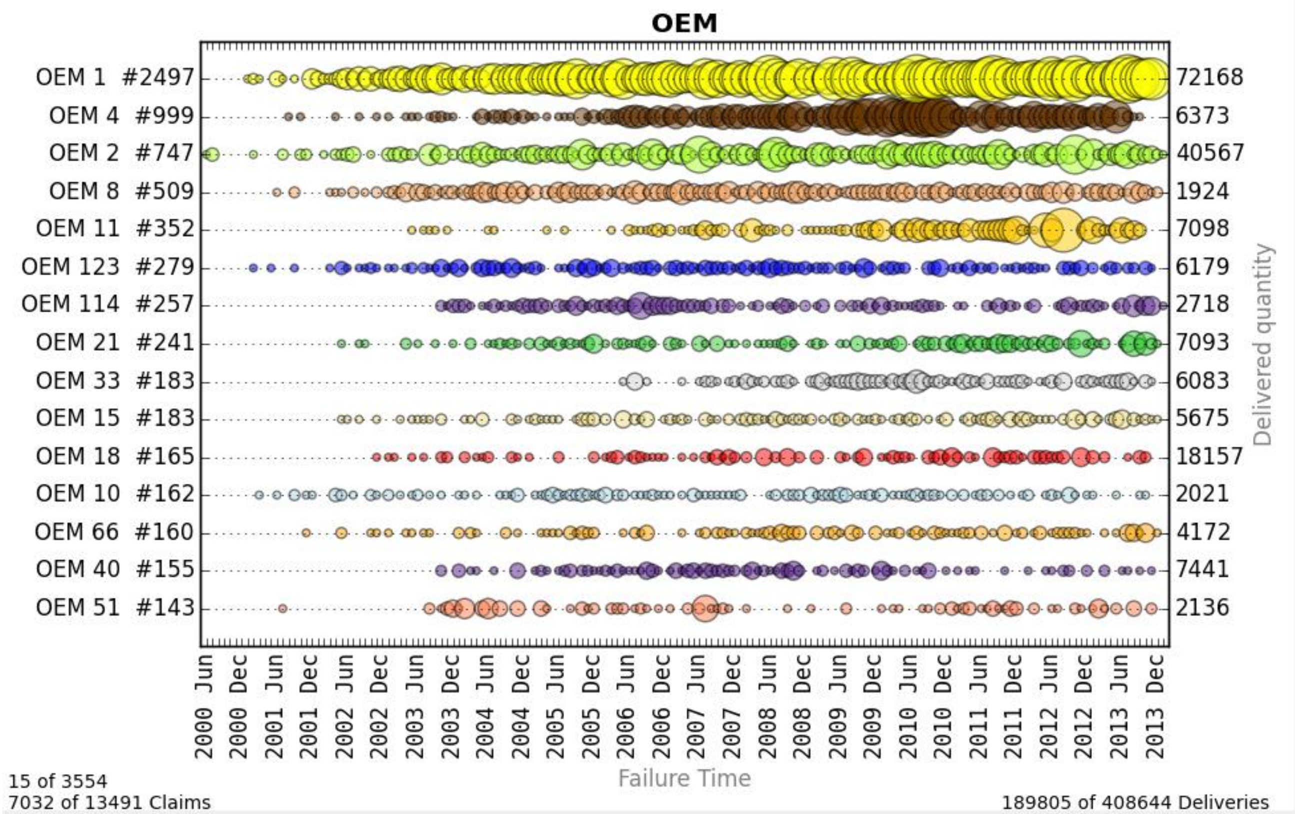

Figure 30:Bubble chart for example with Failure time

The main reasons to analyse the failures with the bubble charts containing the failure time information are:

- ✓ Recognize enviroment problem (identify the time of the year the products are more likely to fail)
- ✓ Identify customer reducing stock
- ✓ Detect if customer is collecting all the products to send them back all together only once, therefore identify the failure data quality (if products wait to be sent all together, you cannot really know the date when the product failed and consequently it can debilitate other analysis as the service time for example)

6.5: Filtering Results

Many bubble charts can be generated in order to seek different information among the failures concentrations that can be filtered afterwards.

The zoom filter can be reached clicking on the Zoom button next to the Export button on the bottom of the tool screen, while visualizing the chart whereby some group information is desired to be filtered. When the Zoom button is clicked, a pop up window with the information on the Y-axis of the bubble chart shows up, and the data to be further filtered can be selected with the check boxes, as seen on next figure:

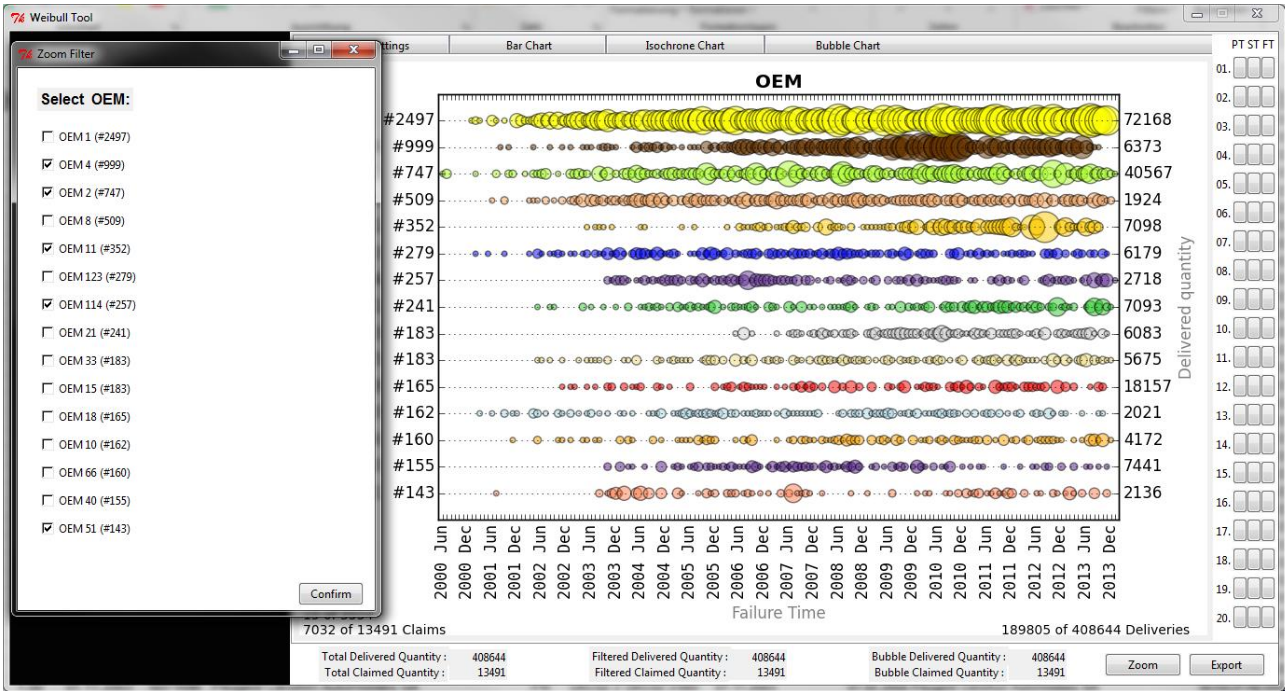

Figure 31: Zoom Filter

After selecting the information using the check boxes, the confirm button on the bottom of the zoom filter window must be pressed so that all the charts can be generated again with the new dataset chosen.

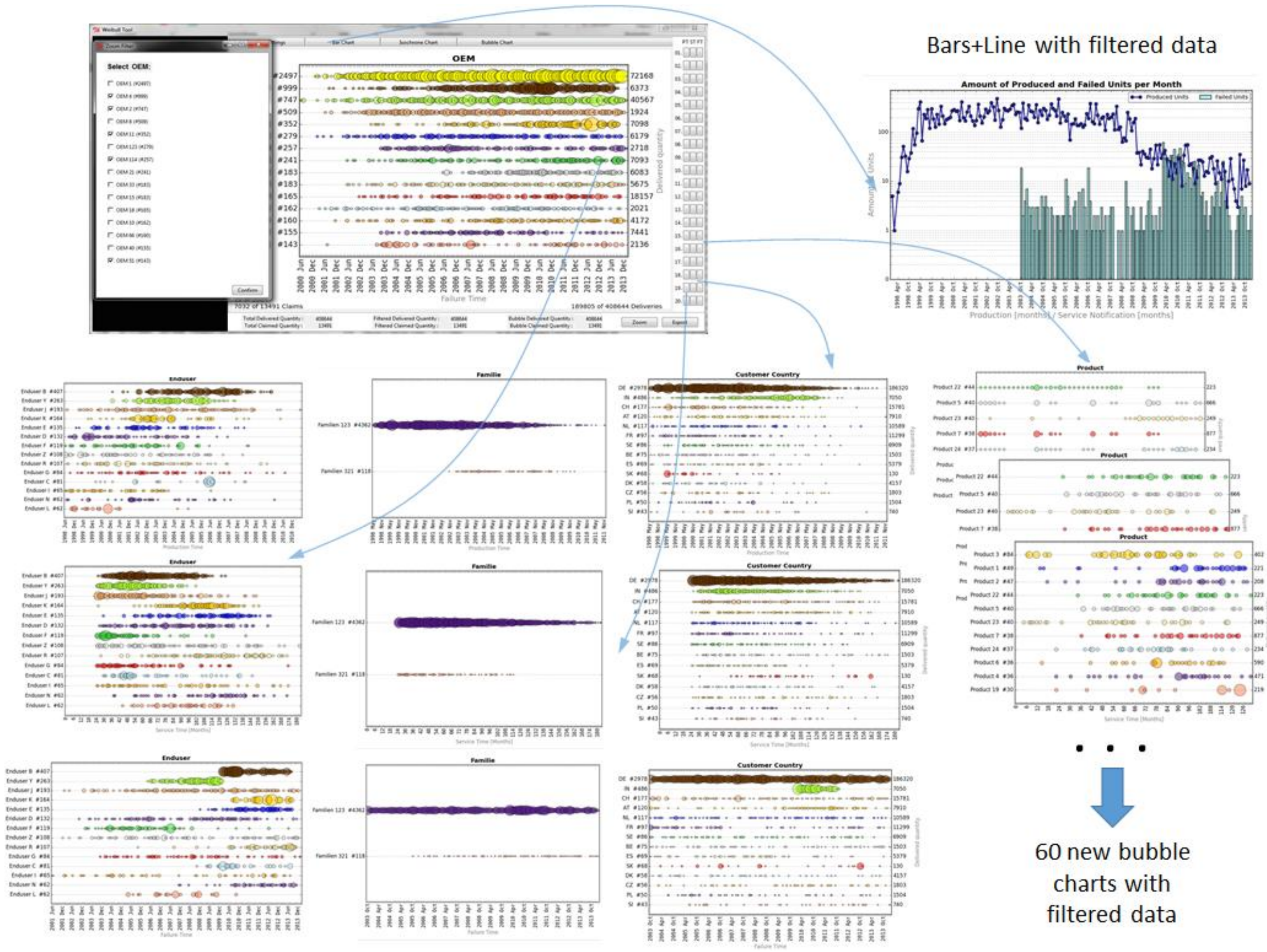

Figure 32: Bubble analysis

If the specific information the user was searching is revealed with the filtered data, the Weibull analysis can be evaluated afterwards clicking on “Weibull” on the left side of the tool screen. The Weibull curve will be generated with the filtered dataset as its input data, and the quality indicators and reliability measures can be visualized and compared. The following figure shows an example of the results expected, in which is represented the whole motivation for the development of this tool.

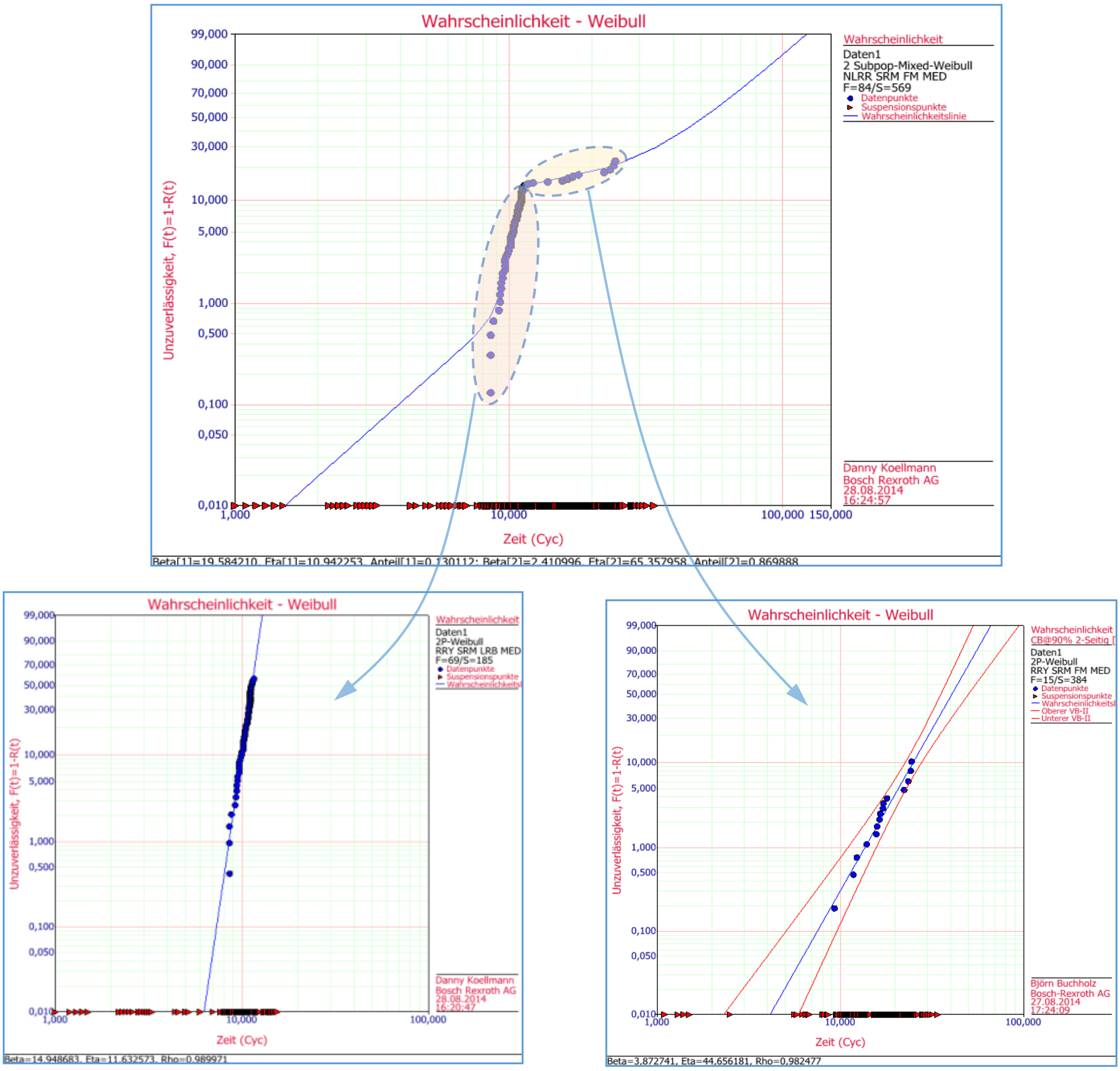

Figure 33: Weibull analysis

The bubble analysis can also be useful to visualize the critical groups of information and select them as an input for the “Multi Curves” on the left side of the tool screen. This feature creates different Weibull curves for each information selected on the settings window of the multi curves.

After the Weibull curve is created showing satisfactory measures, the failure prognosis can be evaluated choosing “Forecast” on the left side of the tool screen.

If the failure forecast created with the data from the past is close enough to the failure prognosis of the real data, then the concept of reliability evaluation is finally concluded.

Chapter 7: Conclusion and Outlook

During this Final Project Work a concept of reliability evaluations was created and as a final result, it was implemented in a software tool for field data visualization and evaluation, integrated with Weibull analysis, in order to support Quality Management and Service Departments of Bosch Rexroth.

The field data analysis tool was developed with the open source programming language Python. The tool presents different approaches of failure data visualization: combination of bar and line chart, isochrones chart, bubble charts and further data filtering feature, which can be used as an input for Weibull analysis in order to get therefore better reliability measures and more accurate failure prognosis.

With the developed tool, Bosch Rexroth can now evaluate its field data and visualize the failure behavior of the product in an easier way integrated with Weibull analysis in one single tool. Due to better products lifetime analysis, which leads to better reliability measurements, the results achieved can help the company to improve the quality and reliability of their products in the future.

Field data uncertainties were one of the difficulties found during the project. The data has to be previously manipulated so that the uncertainties presented sometimes on the data available for the evaluations do not affect the visualization results. Improvements in the quality of field data are expected with the increase of the tool usage.

Additional features can be further implemented in the tool, as other types of graphs and diagrams for the failures visualization, for example. Pie charts, donut charts, histograms, highlight tables, mind maps can be future added to the tool to visualize products failures and find their root causes in a more interactive way.

The tool can be used for field data evaluations that happen every 6 months and the goal for the future is to distribute the tool among other units of Bosch Rexroth worldwide as part of a standard approach of reliability analysis.

Bibliography:

[1] J. Schultz, The Business Case For Reliability. Retrieved December 17, 2015, from http://www.reliabilityweb.com/index.php/articles/the_business_case_for_reliability

[2] Bosch Rexroth AG, „About Bosch Rexroth - Bosch Rexroth AG," [Online]. Available: http://www.boschrexroth.com/en/xc/company/about-bosch-rexroth/about-bosch-rexroth. [Retrieved 15 November 2015].

[3] Bosch Rexroth AG, „Facts and Figures - Bosch Rexroth AG," [Online]. Available: http://www.boschrexroth.com/en/xc/company/about-bosch-rexroth/facts-figures/facts-and-figures. [Retrieved 15.11.2015].

[4] Bosch Rexroth AG, „Products - Bosch Rexroth AG," [Online]. Available: http://www.boschrexroth.com/en/xc/products/index. [Retrieved 15.11.2015].

[5] Robert Bosch AG, Series Quality management in the Bosch Group, No. 6 Evaluation of Field Data, 2001.

[6] Robert Bosch AG, Series Quality Management in the Bosch Group, No. 13 Methods of design for reliability, verification and validation, 2011.

[7] European Standard DIN 13306: Maintenance terminology, 2010.

[8] B. S. Dhillon, Applied Reliability and Quality: Fundamentals, Methods and Procedures, Ontario: Springer, 2008.

[9] M. Sondalini, What is Quality? What does Quality Mean? How do You Know When You Have Quality? [Online Article]. Available: http://lifetime-reliability.com/cms/free-articles/work-quality-assurance/what-is-quality/ [Retrieved 23.11.2015].

[10] P. R. Haviland, Analytical Problem Solving, The Haviland Consulting Group, Grand Rapids, MI (2004, ASQ).

[11] M. Sokovic, D. Pavletic, K. Kern Pipan, Quality Improvement Methodologies – PDCA Cycle, RADAR Matrix, DMAIC and DFSS, Journal of Achievements in Materials and Manufacturing Engineering 43/1 (2010) 476-483.

[12] W. Moser, Product Engineering Handbook, Bosch Product Engineering System, January 2010.

[13] A.L. Hartzell, M. G. da Silva, H. Shea, MEMS Reliability, Springer 2011.

[14] B. Bertsche, Reliability in Automotive and Mechanical Engineering, Berlin: Springer, 2008.

[15] P. Larsson-Brelid, C. Brischke, A. O. Rapp, M. Hansson, M. Westin, J. Jermer, A. Pilgård, Methods of field data evaluation - time versus reliability, May 2011.

[16] R. B. Abernethy, The New Weibull Handbook, Florida: Robert B. Abernethy, 2000.

[17] ReliaSoft Corporation, Life Data Analysis Reference, Tucson - Arizona, generated on May, 2015.

[18] Reliability Glossary, http://www.weibull.com/knowledge/rel_glossary_rs.htm, Online [Retrieved 01.12.2015].

[19] F. Buschmann, R. Meunier, H. Rohnert, P. Sommerlad, M. Stal, Pattern-Oriented Software Architecture, Chichester: John'Wiley & Sons Ltd, 1996.

[20] P. Gries, J. Campbell, J. Montojo, Practical Programming, Second Edition: An Introduction to Computer Science Using Python 3, Dallas: The Pragmatic Programmers, 2013.

[21] M. Hardin, D. Hom, R. Perez, L. Williams, Which chart or graph is right for you? Tell impactful stories with data, Tableau Software, January 2012.

[22] M. A. Barsalou, Root Cause Analysis: A Step-By-Step Guide to Using the Right Tool at the Right Time, CRC Press, 2014.

[23] ASQ – Pareto Chart, http://asq.org/learn-about-quality/cause-analysis-tools/overview/pareto.html, Online [Retrieved 17.08.2015].

[24] Testing based on statistics, Bosch (internal file), 2015.

[25] Machine Design – Unlocking Weibull analysis, [Online] Retrieved 04.12.2015 from http://machinedesign.com/technologies/unlocking-weibull-analysis.