Exploratory Analysis of Truck Reliability Data

Bridging fault reports in testing phase to warranty claims

Master of Science Thesis in the Master's Program "Quality and Operations Management"

ALEXANDER BASMANJI
TARIK OLEVIĆ

Department of Technology Management and Economics
Division of Quality Sciences
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden, 2011
Report No. E2011:105

Abstract

This study should be considered as a link in a long chain of research efforts with the goal of finding a method for predicting warranty claims from test data in the development phases of a new vehicle. It is an exploratory statistical analysis on two product development projects made at Volvo 3P, a business unit within the Volvo group. The goal was to explore the correlation between fault reports in the testing phase and warranty claims. This analysis should serve as a base for a prediction model. The study focused on new and modified parts within the two projects: FH facelift and FMX truck development.

No significant positive correlations were found in this research, which could be good or bad depending on the scope. The authors of this report do however not take stance on the possibility of finding such correlation in other projects. The main concern is the amount of projects studied. It is dangerous to base predictions on a few projects, especially when each project is complex and depends on many different parameters.

Several issues need to be taken into account when analyzing further projects, regardless if the reason is to develop a prediction method or not. First of all, both test reports and claims need to be reviewed and sorted out depending on their consequence on reliability. Secondly, it is problematic to extract data from databases since part lists change frequently with e.g. parts being changed without getting new part numbers. Another issue is whether it is necessary to make this research at part level, as opposed to function group level. This, because groups of parts affect each other and form dependencies while on the other hand, test reports are written on parts. Lastly, the market mix problem needs to be considered. A part can be over-represented during testing and hence provide misleading data.

All these aspects need to be taken into consideration when pursuing further analyses of the same type.

Acknowledgements

This master’s thesis in Quality and Operations Management has been conducted from February 2011 through June 2011, at Volvo 3P.

We express deepest appreciation to our supervisor at Volvo 3P, ***Yngve Neselius***. He did not only lead us as a supervisor but was also continuously supporting and providing information throughout the research. He encouragingly motivated us and provided new learning opportunities and experiences. Without his utmost support, we would have never been able to accomplish this work.

We would also like to sincerely thank ***Ilya Kulinich,*** Feature Reliability Leader at Volvo 3P and ***Hans-Fredrik Henrysson***, Group Manager Durability and Reliability Features, for their valuable support and feedback during the research.

Our endless gratitude also goes to our supervisor at Chalmers University of Technology ***Stefano Barone***, associate professor and expert in statistical methods for providing us with remarkable help during the project. His truthful efforts have made it possible for us to conduct this research.

In addition, we are very grateful to ***Anna-Klara Elmered***, Project Manager Quality, for educating us in the internal Volvo databases and providing us with answers for questions related to these.

Special thanks goes out to everyone at department 26781, Features and Simulation, at Volvo 3P for providing valuable support and information during the project and most importantly for making us feel as a part of the team.

The list of people at Volvo 3P who supported us is long and we thank everyone who hasn’t been mentioned here, however, your help is remembered and appreciated.

Finally, we forward thanks to our friends and family members. Their timely blessings and moral support has encouraged us to successfully complete our Master’s Thesis.

Alexander Basmanji ***Tarik Olević***

Table of contents

1. INTRODUCTION 1
   1.2 Company background 1
   1.3 Research background 1
   1.4 Purpose 2
   1.5 Research Questions 2
   1.6 Delimitations 2
   1.7 Included projects in the research 3
   1.8 Volvo databases used to gather data 4
2. THEORETICAL FRAMEWORK 5
   2.1 Essentials of Reliability 5
   2.2 Reliability Databases and Analysis 6
   2.3 Warranty policy as an insurance and an unforced obligation 8
   2.4 The importance of Warranty databases 8
   2.5 Statistical problems with databases 9
   2.6 Possibilities and issues in reliability prediction 10
3. RESEARCH METHODOLOGY 11
   3.1 Literature research 11
   3.2 Research strategy 11
   3.3 Case study design 11
   3.4 Research design 12
   3.5 Criteria for evaluating research 12
   3.6 Recommendations for data analysis 12
   3.7 On-site observation and expert interview at Hällered proving ground 13
   3.8 Execution of data gathering and analysis 14
4. ANALYSIS 15
   4.1 Analysis of the FH facelift project (P2652) 15
   4.2 Analysis of the FMX project (P2822) 22
5. DISCUSSION 28
6. CONCLUSIONS 30

REFERENCES 31

Appendix 1 I

List of figures

Figure 1: The Volvo Group Organization (Source: Volvo Group webpage)............................ 1
Figure 2. Scheme of the possible correlation between warranty claims and failures in testing. 2
Figure 3: Facelift of Volvo FH16 truck (Source: Volvo Group) 3
Figure 4: Volvo FMX truck (Source: Volvo Group) 3
Figure 5: The areas covered in the theoretical framework. 5
Figure 6: The four classes of data that are typically available during product development, according to Esterman et al. (2005). 7
Figure 7: Typical statistical difficulties emerging when working with databases, as presented by Coit et al. (1986)... 9
Figure 8: An FMX truck undergoing tests at Hällered proving ground (Source: roadtransport.com) 13
Figure 9: The process of the data gathering conducted... 14
Figure 10: Claims by part number, FH facelift project 15
Figure 11: Scatter plot percentage P1 and P2, FH facelift project.. 16
Figure 12: Scatter plot on the percentages (P3) and (P4), FH facelift project 18
Figure 13: Distribution of claims vs. months in service, FH facelift project 19
Figure 14: Claim mileage distribution, FH facelift project 19
Figure 15: Claim mileage distribution, FH facelift project 20
Figure 16: Scatter plot of mileage to failure vs. months in service, FH facelift project 20
Figure 17: Distribution by vehicle assembly date, FH facelift project 21
Figure 18: Number of vehicles produced over one year, FH facelift project.......................... 21
Figure 19: Percentage of claims on produced vehicles over a year, FH facelift project.......... 22
Figure 20: Claims by part number, FMX project.. 22
Figure 21: Scatter plot on the percentages (P7) and (P8), FMX project 24
Figure 22: Distribution of claims vs. months in service, FMX project................................... 25
Figure 23: Relation between mileage to failure and amount of claims, FMX project 25
Figure 24: Scatter plot of mileage to failure vs. months in service, FMX project 26
Figure 25: Distribution by vehicle assembly date, FMX project 26
Figure 26: Distribution of vehicle assembly date, FMX project... 27
Figure 27: Percentage of claims on produced vehicles over a year, FMX project.................. 27

List of tables

Table 1: The highest contributing parts to customer warranty claims, FH facelift project...... 16
Table 2: The highest contributing parts to L protuses, FH facelift project 17
Table 3: Summary of vehicles and claims, FH facelift project 18
Table 4: The highest contributing parts to customer warranty claims, FMX project 23
Table 5: The highest contributing parts to L protuses, FMX project...................................... 23
Table 6: Summary of vehicles and claims, FMX project.. 24

List of abbreviations

KOLA	KOnstruktionsdata LAstvagnar (Design data trucks)
PROTUS	PROtotype follow Up System
QWAT	Quality Warranty Analysis Tool

1. INTRODUCTION

This first chapter will give the reader information on the background for the research, such as information about the Volvo Group, why the research is conducted as well as presenting the scope for the project.

1.2 Company background

Volvo 3P is a Business Unit within the Volvo Group. It combines the resources of the four truck companies; Mack Trucks, Renault Trucks, Volvo Trucks and UD Trucks in the areas of Product Development, Product Planning, Purchasing and Product Range Management (see figure 1). The goal is to synergize the common resources within the group while at the same time ensuring a competitive offer and preserve the unique distinction and characteristics of each brand. Nearly 5000 people at eight geographic sites around the world are working at Volvo 3P and it is therefore fair to say that the company is the largest development organization in its field when considering the size and niche. At the time of this paper being written, Volvo 3P is celebrating 10 years of operation (The Volvo Group, 2011).

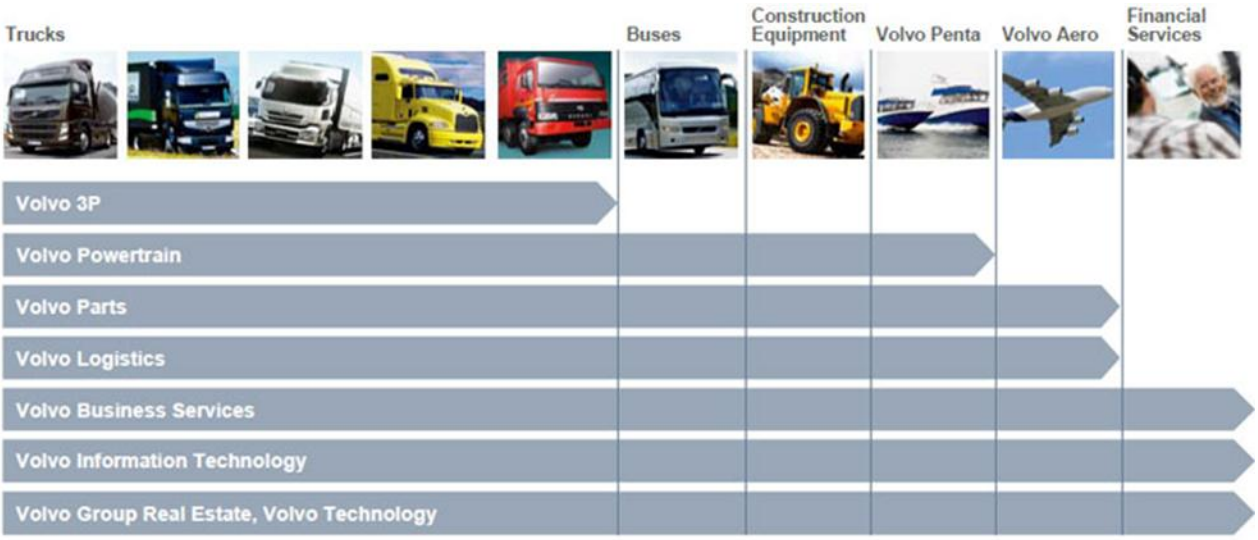


Figure 1: The Volvo Group Organization (Source: Volvo Group webpage)

1.3 Research background

The background for this project is Volvo's interest in developing a method for estimating the amount of warranty claims based solely on the internal testing reports. Previous research that has been conducted at the department has resulted in a fault prediction method for product development (Kulinich & Tufail, 2008). While the work by Kulinich and Tufail (2008) is mathematically oriented the research conducted at the same department by Andersson & Lykken (2006) is more theoretical and their main conclusion is that the reporting and follow-up system has the most development potential, whereas the importance of the validation and verification phase in the product development (PD) process is addressed. In this phase the complete vehicle is driven and tested in conditions that are supposed to be as similar to customer usage as possible.

The interest in these tests is for the product development department to know, how to in advance estimate the number and type of faults that occur in different phases of PD process. The reason behind predicting the number of faults is the project managers' interest in knowing how many fault reports might occur at different phases of the project so they can take right decisions on time regarding resource allocation and proactive work. Eventually, this may result in reduced testing effort which in turn has a positive impact on the project lead time and cost (Tufail, 2008).

With this background the research at hand will further address the area of reliability testing and researching existing theoretical frameworks and theories and a statistical analysis of historical data.

1.4 Purpose

The purpose of this research was to make an exploratory study on two different projects in order to find what type of correlation exists between test reports and customer warranty claims. Further, the research will serve as a basis for developing a method for predicting the amount of warranty claims based on internal Volvo 3P reliability testing results.
A scheme of the possible correlation between warranty claims and failures in testing is depicted in Figure 2. The ideal situation occurs when we find few failures in testing and few warranty claims. It is also acceptable if there is a high number of failures in testing correlated to low number of warranty claims. This means that the efforts made in product development are fully repaid. An unwanted case is the opposite i.e. when few failures in testing correspond to high number of warranty claims. Such situation, if occurring, would be symptomatic of wrong development/testing management. The worst case would occur if we find high number of failures in testing correlated to high number of warranty claims. In such a case, the big efforts in development/testing are not repaid at all in the real usage of the developed system. From the picture we notice that positive correlation is not necessarily “good” and conversely negative correlation is not necessarily “bad”.

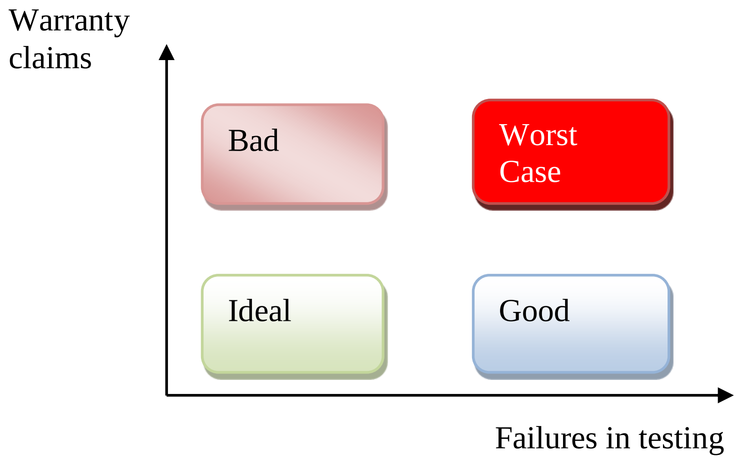


Figure 2. Scheme of the possible correlation between warranty claims and failures in testing.

1.5 Research Questions

- Is there a positive correlation between test reports and customer warranty claims in the projects chosen for this research?
- Is it possible to develop a method for calculating the amount of warranty claims solely based on test reports?

1.6 Delimitations

The report will be limited to two Volvo 3P product development projects of different nature (the FH facelift and FMX projects). During the analysis of these projects, only parts that have been modified or newly developed within the project will be considered and further correlated to customer warranty claims. The research will only concern test reports generated by rig tests, field tests, and proving ground test, so called L-protuses. The related warranty claim data is limited to a time period of 12 months in service date for each truck.

1.7 Included projects in the research

In this section the FH facelift and the FMX projects are shortly presented.

FH Facelift project (internally at Volvo: P2652)

The goal of the P2652 project was to perform a facelift on the cabin of the FH vehicles in Volvo's product line (see figure 3). The facelifted models were introduced to market by the end of 2008.

Figure 3: Facelift of Volvo FH16 truck (Source: Volvo Group)

FMX project (Internally at Volvo: P2822)

The goal of the P2822 project was the introduction of a new truck to the market, the FMX (see figure 4). It is a version of the FM truck, aimed for construction purposes. The FMX truck was divided into parts, distribution and construction, and introduced to market by the end of 2010. Due to the limited time the truck has been on the market it is not enough data to fully conduct a useful study. Therefore, by analyzing the FH/FM trucks 12 months period before introducing the FMX truck the result can serve as an indication for the FMX truck performance. It can also be of value when comparing and evaluating the reliability performance before and after production start.

Figure 4: Volvo FMX truck (Source: Volvo Group)

1.8 Volvo databases used to gather data

In order to gather the necessary data used for the research, data was extracted from three different internal Volvo databases. The first database is the reliability test report system PROTUS, which is an abbreviation for PROTotype follow-Up System. The PROTUS system is a database that contains information about all reported errors found during the testing of trucks and parts, either in test rigs, field tests or on the testing grounds. Following the name of the database, one or several test reports are popularly called a protus or several protuses. In order to make it easier for the reader, upper case characters will be used when referring to the database itself (PROTUS) and lower case characters when referring to the test reports (protus/protuses).

During data gathering from the PROTUS system it is important to have pointed out the targets of interest i.e. the new and modified parts. These part lists were extracted using the KOLA system, which is an abbreviation for KOnstruktionsdata LAstvagnar (design data trucks). The KOLA database is a system where all truck parts, object relations and projects are listed.

The third part of data gathering concerns the customer warranty claims and need to be collected from the QWAT system (Quality Warranty Analysis Tool). The QWAT system contains information on all warranty claims reported for all Volvo trucks around the globe with additional detailed information of the circumstances regarding the truck and the warranty claims.

2. THEORETICAL FRAMEWORK

This chapter will set the scope for the theoretical framework used throughout the research project. It starts with explaining the basics of reliability and what it means to have reliable products, in order to continue with the meaning of reliability databases and the problems related to them. Finally, the chapter will clarify what defines a warranty policy, how warranty databases can be handled and how to make predictions of warranties. The chapter is graphically described in figure 5.

Figure 5: The areas covered in the theoretical framework.

2.1 Essentials of Reliability

Reliability can be defined as *"The probability that an item will perform a required function without failure under stated conditions for a stated period of time"* (O'Connor, 2002). Naturally, a traditional reliability analysis therefore implies ensuring that a product can perform the specified function in the designated environment for a minimum length of time, cycles or actions. This requires thorough testing in order to verify that the product is designed and built to have an acceptable life length (Ireson, Coombs Jr, & Moss, 1995).

However, it has been noted that this approach to reliability can be inconsistent since the main objective during product development is to maximize the improvement in reliability, not necessarily to characterize it. Moreover, in order to maximize the reliability, many systematic changes to the design configuration are required, which makes extensive reliability testing early in the development process impractical. When it becomes practical, it is too late in the development phase to take the appropriate actions (Clausing, 1994).

Characterization of reliability during product development is nevertheless very important. But there is a need for methods that can be integrated into the decision-making process so that they help to improve the reliability performance of the product while at the same time monitoring the improvement. This kind of methods will allow the reliability performance to be linked to the financial targets of the project (Esterman, Gerst, Stiebitz, & Ishii, 2005).

Whether failures occur or not and their times to occurrence, can seldom be forecasted accurately. Reliability is therefore an aspect of engineering uncertainty, whether an item will work for a particular period is a question which can be answered as a probability (O'Connor, 2002). The main problem is that early in the development process there is little direct statistical evidence to predict reliability and the existing prediction models fail to provide the required accuracy (Esterman, Gerst, Stiebitz, & Ishii, 2005).

Testing is however an essential part of any engineering program. Reliability testing is necessary because designs are seldom perfect and because designers cannot usually be aware of, or be able to analyze, all the likely causes of failure of their designs in service. Reliability testing should be considered as part of an integrated test program, which should include functional testing, to confirm that the design meets the basic performance requirements but also environmental testing (O'Connor, 2002).

Reliability can also be viewed upon in the opposite way i.e. it can be expressed as the number of failures over a period of time, hence the term *fault frequency* that is in popular usage at production companies, such as the Volvo Group. This is also according to O’Connor (2002) the main objective of reliability engineering to apply engineering knowledge and specialist techniques to prevent or to reduce the likelihood or frequency of failures. The rest of the objectives are sorted by importance. Second, identify and correct the causes of failure that does occur despite the efforts to prevent them. Third, determine ways of coping with failures that does occur, if their causes have not been corrected. Lastly, address how to apply methods for estimating the reliability of new designs, and for analyzing reliability data.

Durability on the other hand is a particular and distinct aspect of reliability, describing the ability of an item to withstand the effects of time (or distance travelled, operation cycle, etc.) that implies parameters such as fatigue, wear, corrosion, electrical parameter change, etc. Durability is usually expressed as the minimum of time before the occurrence of wear out failure (O'Connor, 2002).

2.2 Reliability Databases and Analysis

When working with reliability, one will most certainly end up gathering and processing large amounts of data. Typically, the use of databases and the subsequent statistical analysis are, according to Coit et al. (1986), used for the following reasons:

a) Creating a model for forecasting, studying or controlling a given component.
b) Evaluation of the reliability of a given component by some relevant measure, e.g. mean time between failures, down time etc.
c) Extrapolation of reliability parameters to assess expected rework, warranty claim costs etc.

Alsultanny (2010) states that a database is a form of indispensable and effective information management tool since, it provides a range of services for effective storage and retrieval of data. The primary function of a database is to provide timely and reliable information that supports the daily operations of an organization.

Esterman et al. (2005) counts to four classes of data that is typically available during the development of a complex system, as shown in figure 6. The first class is **historical field data** in the form of service records. The value of these data is that they are representative of actual customer and field behavior. However, it can be considered “dirty” data since some organizations measure and reward service personnel based on the amount of time it takes them to resolve a customer problem. If the problem is not solved correctly, it does not affect the reward system. That being said, it is a valuable data source that must be taken advantage of.

Product development testing data is conceived from the testing conducted during the product development process. These include feasibility testing, tests aimed at defect discovery, reliability growth testing, individual subsystem testing, component testing and system integration testing. These data represent the cleanest data as they are under the direct control of the product development enterprise. The challenge with these data is however that they may not be fully representative of the conditions under which the product is used.

Failure assessment tools such as FMEA, fault tree analysis and physics of failure models all provide valuable insight to identifying significant risks. Although this kind of data is valuable, it tends to be less quantitative in nature and need special treatment.

Engineering judgment is when the human capacity of noting patterns and processing vast amounts of complex and disparate data to arrive at valuable conclusions is in process. Given the complexity of the systems under development and the complexity of predicting warranty performance, it is imperative that engineering judgment be appropriately included in any modeling activity.

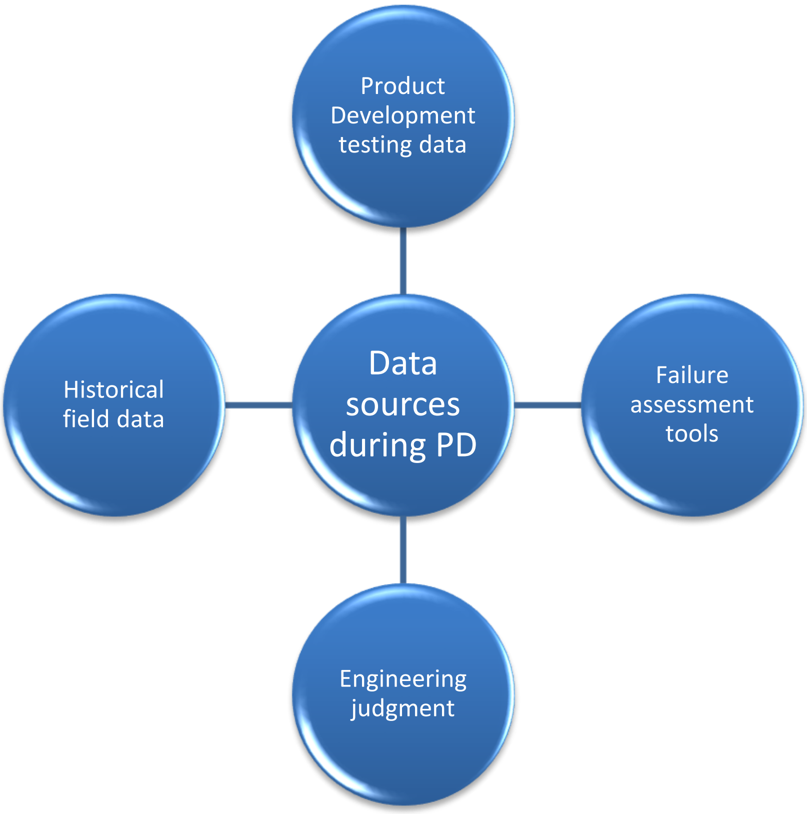


Figure 6: The four classes of data that are typically available during product development, according to Esterman et al. (2005).

Even though test data is typically of high statistical quality, the data is still of limited value to reliability analysis concerning operational reliability according to Coit et al. (1986). The writers state that the reason for this is the differences between life tests and actual operation and even if component life tests use accelerated endurance tests to get probable results, in general only a few stress parameters are applied. This is the main difference with operational usage, where a component (and the equipment it is installed in) is inflicted by temperature, voltage, shock, vibration, power cycling, humidity, electro-magnetic inference etc.

Coit et al. (1986) further states that life test data indeed is not useless in reliability studies, but that the use may be limited depending on the goals of the study. On the other hand, it is claimed that field data can only provide reliability information on parts which have been available for at least “a couple of years”.

When implementing the use of a database, there are several tasks that need to be undertaken, e.g. data acquisition, data reduction and summarization, computer entry, updating of information and quality control. Coit et al. (1986) underlines that updating a database can be difficult especially for field data tracked over a longer period, because parts lists can change frequently.

2.3 Warranty policy as an insurance and an unforced obligation

A warranty can be defined as “… a contractual obligation between a consumer and manufacturer that protects the consumer should the product fail to perform its intended function within a given time period” (Esterman, Gerst, Stiebitz, & Ishii, 2005).

Offering a warranty is hence an extra insurance for the customer and is also used as a marketing tool to help increase sales of a product. However, a challenge for most manufacturers is that as selling prices drop, the unit costs needs to be cut which results in warranty costs becoming an increasing part of the product cost. An item resolved under warranty can incur the following costs to the manufacturer: administration costs, transportation costs, repair/replacement costs, handling costs, and spare parts inventory costs. Therefore, in order to stay competitive, it is necessary to make improvements in product reliability (Esterman, Gerst, Stiebitz, & Ishii, 2005).

Organizations often only focus on the analysis of product failures when working with understanding and reducing warranty costs. It is important to notice however, that warranty costs can be a product of misaligned customer expectations that has nothing to do with product failure. Because of this, improving product reliability does not always solve a warranty problem and there are other contributors to increased warranty costs (Esterman, Gerst, Stiebitz, & Ishii, 2005; Lu & Chiang, 2008).

2.4 The importance of Warranty databases

Warranty databases provide information on a product’s performance in real field conditions. Hence, many manufacturers have recognized the importance of collecting and analyzing field failure data as a way of making their products more reliable. It is pointed out that if such information is well analyzed and communicated, then it will not only reduce the recurrence of old problems in new products, but also the expenses on recalls, repairs, warranties, and liabilities (Mesbahul & Suzuki, 2009).

When a product fails, different types of failure modes are observed. Some failures are time dependent, some are usage dependent, and some depend on both. A common example of such products is the automobile whose life is measured by both time in service and mileage. Therefore, there are two important reliability analyses of products using warranty data: age-based (e.g. time), and usage-based (e.g. mileage) (Mesbahul & Suzuki, 2009).

The usage time distributions of non-failed products are different from those of failed products. This gives the conclusion that mileage-based analysis using warranty databases usually requires additional data because mileage distributions of automobiles that fail during the warranty limit differ from those of automobiles that have not failed during the period (Mesbahul & Suzuki, 2009)

2.5 Statistical problems with databases

Common statistical problems emerge regardless of what kind of data is stored in a database. Coit et al. (1986) lists five difficulties, as visualized in figure 7.

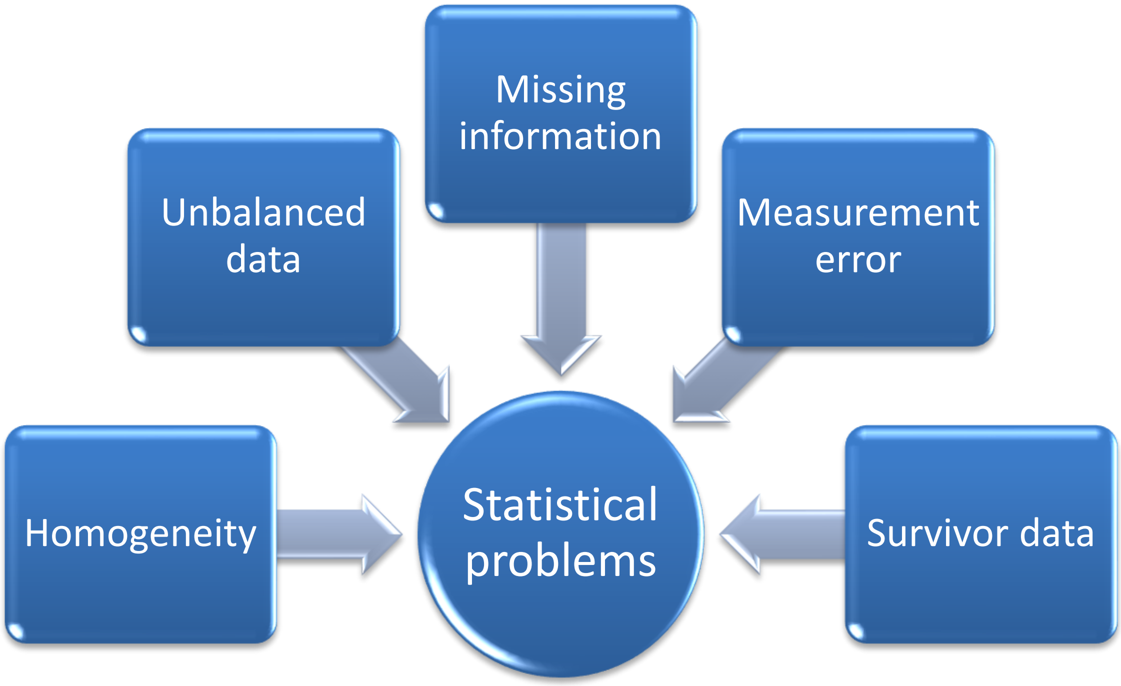


Figure 7: Typical statistical difficulties emerging when working with databases, as presented by Coit et al. (1986).

Homogeneity – Even when the data is carefully defined and sorted there is a variation present between and within the sources. The reason is the large number of uncontrolled and unknown sources that still affect the given component or system. Even when there is a single source, engineering changes such as part changes will decrease the homogeneity.

Unbalanced data – Field data is obviously affected by different environmental and operational influences. In order to facilitate analysis, the sample should be balanced according to each of these factors. This results in an increased size of the database in order to balance the data and make it statistically valid.

Missing information – Since data is usually recorded at discrete inspection intervals, which may be defined by maintenance intervals, it will be hard to define individual failure times and the analysts are forced to look at groups of failures in time intervals. This missing information will inflict the resolution of the analysis negatively. This kind of grouped data results is referred to as “window” data by Coit et al. (1986), since it is sampled in windows of time.

Measurement error – Is a wide category that includes various sources of error in measuring and recording failure data that varies depending on the application. It might be random sampling error such as noise, or systematic, such as the window data mentioned above.

Survivor data – Typically, a life test is terminated before all items on test have failed. Hence, survival times are the operation times of the items which did not fail and these might contain interesting information. By taking the survivor data into consideration, one will estimate reliability parameters for the whole population, rather than the early failures only.

Coit et al. (1986) points to the fact that the problems discussed can be accommodated by being aware of them and by carefully analyzing them. Ansell & Phillips (1990) underlines that statistical methods should be a tool to achieve a given end, and might therefore play a role in assessment, identification or prediction. Hence, the problems presented by Coit et al. (1986) can be tackled in various ways, depending on the goal of the analysis, but also the time frame and/or other priorities of the specific project.

2.6 Possibilities and issues in reliability prediction

Reliability prediction is one of the most common forms of reliability analysis, usually employed at the earlier design stages, in order to evaluate inherent reliability of product design as well as to identify potential reliability problems (Kleyner & Bender, 2003).

However, due to several factors, pinpointing the reliability that a certain warranty event will occur is complex and not a straight-forward task. One of the causes for this is related to the particular market segment the product is in, making representative testing during development difficult. It might also be that the technological and design decisions are so different from past decisions that using historical data is troublesome (Esterman, Gerst, Stiebitz, & Ishii, 2005).

The typical approach to warranty prediction is to start with the warranty data for the most similar product already in the field to the one under development (Lu & Chiang, 2008; Esterman, Gerst, Stiebitz, & Ishii, 2005). However, Esterman et al (2005) suggests that the event rate prediction models need to better integrate historical field experience, product development testing data, assessment tool information, and engineering judgment.

In the same report it is also stated that the prediction of warranty performance during the product development phases has two main objectives. The first objective is to facilitate decision-making by increasing the product developers' and managers' confidence that their actions are leading to improved warranty performance in the field. In addition, these models should provide insights to the development team for actions they can take to mitigate costs. The second main objective of warranty performance prediction is that it must provide the management team an accurate projection of warranty costs so that the enterprise can appropriately plan for the financial impact of these costs. These impacts include product pricing, extended warranty support pricing, service inventory requirements, warranty accrual, etc (Esterman, Gerst, Stiebitz, & Ishii, 2005).

Once a prediction model is built, a company can apply it to figure out the volume prediction of warranty returns and to prepare the necessary spare parts and resources so as to maintain the warranty returns. The warranty cost obviously rises when there is a serious quality issue taking place in the field and an epidemic failure incurs even more expenses to resolve (Lu & Chiang, 2008). Warranty returns provide a basis to determine the field use failure distribution. They also contain feedback on quality performance, or enable predictions for quality spills as well (a quality spill is a manufacturing problem not detected by existing manufacturing controls). The difficulty in predictions relates to how one account for all parts in service via a suspended sample strategy. Statisticians are reluctant to work with incomplete samples due to the inaccuracies resulting from not properly considering these un-failed samples. Failure definitions can be unclear and repair orders so non-descriptive that it is difficult to properly class a failure. These issues must be kept in mind, but not paralyze an analyst from making reasonable assumptions to enable an analysis with thinking, and recognize the intelligence that can be gathered from the analysis (Aldridge, 2006).

3. RESEARCH METHODOLOGY

The research methodology chapter will describe the line of action taken to conduct the research, from the preparation of the study with knowledge gathering, through the research set-up, to the data analysis.

3.1 Literature research

In order to get the appropriate background knowledge on warranties, reliability tests and warranty prediction a literature research was performed. The main sources were the databases at Chalmers Library as well as journals recommended by the supervisor. Other sources were books in the subject as well as previously conducted theses reports in the same area.

Academic internet search engines were used to search for appropriate articles, using the keywords; warranty prediction, warranty costs, prediction model warranties, automotive, reliability, reliability testing, reliability engineering, reliability data analysis, product development. The search engines used were Chalmers Library's Summon, which covers 500 million articles from scientific papers and journals, as well as Google Scholar.

The journals that were more specifically searched through were IIE Transactions/RFL and IEEE Transactions on Reliability. These two journals were combed through, every issue that was published for the last two years were checked for relevant articles as well as searching all issues with the keywords mentioned above.

3.2 Research strategy

Because of the nature of this study, being based on statistical data, it is scientifically classified as a quantitative research strategy. The quantitative research strategy emphasizes quantification in the collection and analysis of data and entails a deductive approach to the relationship between theory and research, in which the accent is placed on the testing of theories (Bryman & Bell, 2007).

The theory in this case is that there is a correlation between reliability test reports and warranty claims in the field. The theory guides the research such that it decides what kind of data is needed to be collected. This data leads to observations and findings which enables the testing of the original theory.

3.3 Case study design

In order to find a possible correlation between reliability test reports and warranty claims, it is obvious that several projects needs to be looked into in order to draw some kind of generalizable conclusions. Scientifically, this kind of approach is called a multiple-case study and is largely undertaken for the purpose of comparing the cases that are included. A multiple-case study allows the researcher to compare and contrast the findings deriving from each of the cases. This facilitates for the researchers to consider what is unique and what is common across cases, thus clearing the way for sustainable conclusions (Bryman & Bell, 2007).

3.4 Research design

The comparative design represents a distinct form of research design that forms the study by using more or less identical methods of two or more contrasting cases (Bryman & Bell, 2007). In this particular study, the different cases are as mentioned previously, two different product development projects at the Volvo Trucks Corporation.

The research conducted can basically be described as a four-step job. The new and modified parts in each project were first identified using the KOLA database at Volvo, a database containing details about every part being used in the organization. Secondly, the prototype test data system was checked for these new parts in order to see how many test reports were written for every part. The third means checking the warranty claims database for the same parts in order to see how many warranty claims were reported for each part. Finally, analyses are conducted by synergizing the data from the databases in order to compare and find the correlations between them.

3.5 Criteria for evaluating research

Bryman & Bell (2007) suggests three main criteria for evaluating business research, namely reliability, replication and validation.

Reliability is concerned with the question of whether the results of a study are repeatable. In a quantitative study, the main concern is usually whether a measure is steady or not. In this particular study however, the failure rate measure is based on whether a part on a truck is broken or not which makes for a consistent and hence, a reliable measure.

In order for a study to be replicable, the procedures need to be described and accounted for in great detail. This will enable other researchers to redo the same study, should they e.g. want to control the results. The transparency which implies replication is closely connected to reliability, since a transparent and replicable study makes it easier to control the reliability.

Validity is concerned with the integrity of the conclusions made in a study, for example if the causal relationship between two or more variables holds water. If for example it is implied that x causes y, can we be sure that x is the reason for the variations in y and not something else? Another concern can be if the results can be generalized beyond the specific research context.

3.6 Recommendations for data analysis

Ansell & Phillips (1990) describe a straight-forward approach of analyzing data, which is suitable as a valid starting-point.

They recommend starting off with simple plots and statistics and then continue with more detailed analyses based on the results. As previously mentioned, the authors underline the fact that the objective must always be in the center of attention for the analysts and the data itself should not be allowed to define the whole analysis. The first stage of data analysis is inspection and validation where the data have to be controlled for inconsistencies and possible errors. It is recommended specifying the observed lifetimes being less than the period studied and checking if values are genuine repeats.

The subsequent step is to plot the data and the author's stress that one should always start with simple plots. A Pareto or distribution plot can reveal interesting information in a reliability analysis e.g. reveal outliers and the main characteristics of the data collected. An outlier may exist because of errors in collection but it may also reveal interesting information about the process. Further, statistical analysis is an iterative process and when applying a technique to a data set it often turns out that another technique will become appropriate. However, a careful examination of the data needs to be done before choosing a technique.

Depending on the data, it is also possible to investigate the relationship between two variables, so called bivariate relationships. A bivariate scatterplot of lifetimes against lagged lifetimes may reveal any notes of dependency. In order to allocate differences in the data, box-whiskers or scatterplots can be used. It is recommended to continue with further basic analysis, such as mean, median and standard deviation (Ansell & Phillips, 1990).

3.7 On-site observation and expert interview at Hällered proving ground

When working with large amounts of data, it is easy to get blinded by the numbers and lose the meaning of what the numbers stand for. By visiting the proving ground at Hällered, a test track owned by Volvo Cars Corporation but jointly used with the Volvo Group and other automotive manufacturers, an insight and deeper understanding of the testing was gained. The test track at Hällered has a number of different obstacles that test the trucks in different ways, one of them is shown in figure 8. Two test drivers were followed and observed during tests of two different trucks, where they had the chance to freely speak of the way they write protus reports. In addition to this, the test engineer at the track was interviewed for the purpose of clarifying how the protuses are classified and sorted. The interview can be considered as a semi-structured interview (see appendix 1), based on a few open questions and conducted like an informal conversation. The results of the interviews are not presented separately, but are implemented in the analysis.

Figure 8: An FMX truck undergoing tests at Hällered proving ground (Source: roadtransport.com)

3.8 Execution of data gathering and analysis

In order to gather the necessary data from the reliability test report system PROTUS it is necessary to undergo an education and tutorial, thus enabling independent usage of the system since it is not available for all personnel at the Volvo Group. During data gathering from PROTUS it is important to have established what type of information that should be extracted. Since the scope of the project was limited to new and modified parts a first extraction had to be done from the KOLA system. After obtaining a list of created or modified parts for each project it is possible to run these part lists in the PROTUS system so that a list of all test reports can be obtained, see figure 9.

In parallel to this, the data gathering concerning the customer warranty claims also need to be collected from the QWAT system. When extracting data from the QWAT system it is important to specify which parts of certain projects and during which time period the data should consider. By having a complete list of all relevant parts from the KOLA system it is simpler to extract this data. Since the QWAT system is restricted and the data extraction is time consuming it is necessary to have made the right selection of relevant parts.

Using the data extracted from one database as input in another was not without problems, since the databases are completely different in nature and incompatible with eachother. For example, using a part list from the KOLA database to extract warranty claims in QWAT meant running a separate script in order to produce a string of the part numbers compatible with QWAT.

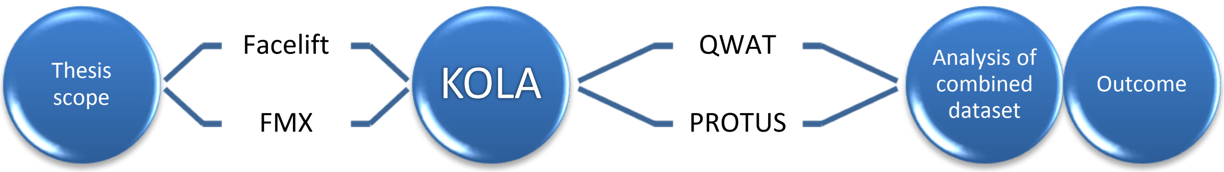


Figure 9: The process of the data gathering conducted

4. ANALYSIS

After gathering the necessary data needed to make an exploratory analysis of the two projects, the results are presented in the following chapter. The analyses is conducted with two different perspectives, the first is to analyze the warranty claims data and then correlate it to the test report data, the second perspective is to first analyze the test report data and then correlate it to the warranty claims data. The analysis is divided with these two perspectives since the two data sets are independent of each other and it is important to analyze the datasets from different standpoints. By using different perspectives the expectations are to find any correlation between the two data sets. It is also important to consider the fact that there might not be a correlation in one of the two ways. The two data sets will incorporate information about part numbers, months in service, mileage to failure and vehicle assembly date.

4.1 Analysis of the FH facelift project (P2652)

For the FH facelift project (P2652) the warranty claims data is collected from September 2008 until September 2009. The Internal testing data is not limited by any timeframe but instead limited to the project scope.

Warranty claims as viewpoint.

With this perspective the first step is to find the parts that have the most warranty claims. By using Pareto chart and the Pareto principle, 19 parts where discovered as the biggest contributors to warranty claims, see figure 10.

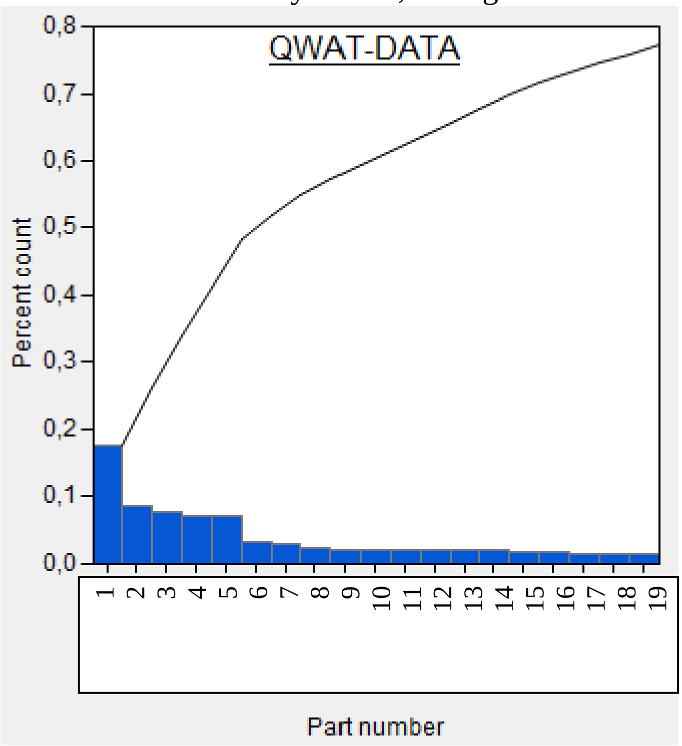


Figure 10: Claims by part number, FH facelift project

The 19 parts are only 4.4% of the 430 parts created and modified in the project but generates 80% of all the warranty claims. By comparing these part numbers to the PROTUS dataset it is possible to see the relation between warranty claims and test reports. As showed in table 1, 15 of 19 parts has recorded failure during testing, 741 warranty claims can be correlated to 73 L-protuses which is 26% of the total amount of protuses written in the project. As an example, the part with the most warranty claims only has one protus and the part with the most protuses only generates 32 warranty claims.

Table 1: The highest contributing parts to customer warranty claims, FH facelift project

Part Name	No. Claims	Percent (P1)	L Protuses	Percent (P2)
1	169	0.18	1	0.0036
2	84	0.088	2	0.0071
3	74	0.077	1	0.0036
4	69	0.072	13	0.0461
5	69	0.072	5	0.0177
6	32	0.033	20	0.0709
7	29	0.030	1	0.0036
8	24	0.025	4	0.0141
9	21	0.022	1	0.0036
10	20	0.021	11	0.0390
11	20	0.021	0	0
12	20	0.021	3	0.0106
13	19	0.02	7	0.0248
14	19	0.02	0	0
15	17	0.018	2	0.0071
16	16	0.017	1	0.0036
17	13	0.014	1	0.0036
18	13	0.014	0	0
19	13	0.014	0	0
Others	218	0.221	209	0.741
Total:	959	1	282	1

In figure 11, a scatter plot shows the relation between the percentage of warranty claims (P1) and percentage of protuses (P2).

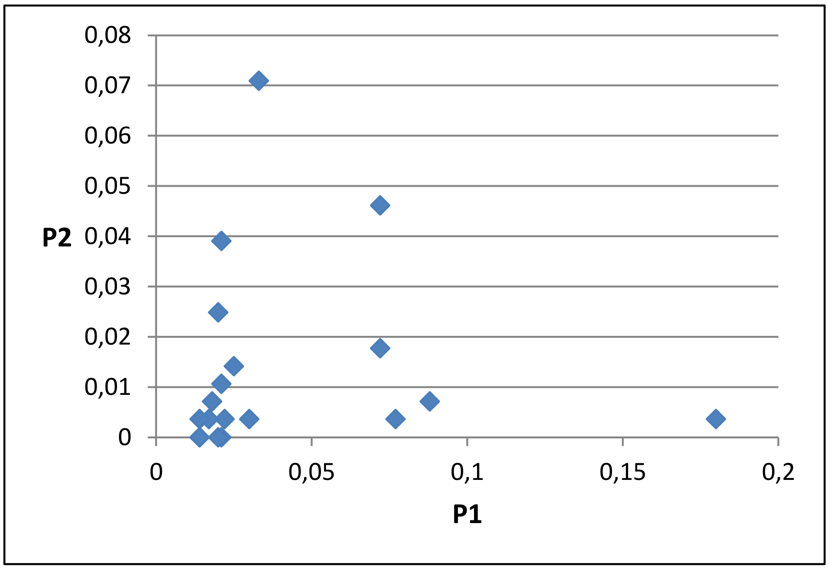


Figure 11: Scatter plot percentage P1 and P2, FH facelift project

Conclusion: From this first step, no strong relationship between the amount of warranty claims and protuses was observed.

Protuses as viewpoint

With this perspective, the first step is to establish which parts have the most protuses written on them. When applying the Pareto principle and using Pareto chart 28 parts where discovered as the largest contributors to protuses, 28 parts generated 213 protuses which is 80% of the total amount of protuses written in the project. As shown in table 2 the 213 protuses can be correlated to 296 warranty claims distributed from 19 of the 28 parts. These 296 warranty claims is only 30% of the total amount of warranty claims. As an example one part with 20 protuses generated no claims, in comparison to the part with 5 protuses that generated 69 warranty claims.

Table 2: The highest contributing parts to L protuses, FH facelift project

Part No.	No. L Protuses	Percent (P3)	No. Claims	Percent (P4)
1	20	0.0709	32	0.0333
2	20	0.0709	0	0
3	18	0.0638	4	0.0042
4	15	0.0532	3	0.0031
5	14	0.0496	3	0.0031
6	13	0.0461	0	0
7	11	0.0391	7	0.0073
8	9	0.0319	69	0.0719
9	9	0.0319	20	0.0208
10	7	0.0248	19	0.0198
11	7	0.0248	5	0.0052
12	6	0.0213	4	0.0042
13	6	0.0213	2	0.0021
14	5	0.0178	1	0.0011
15	5	0.0178	0	0
16	5	0.0178	0	0
17	5	0.0178	69	0.0719
18	4	0.0142	0	0
19	4	0.0142	24	0.0251
20	4	0.0142	0	0
21	4	0.0142	0	0
22	4	0.0142	0	0
23	3	0.0106	2	0.0021
24	3	0.0106	10	0.0104
25	3	0.0106	20	0.0208
26	3	0.0106	1	0.0011
27	3	0.0106	1	0.0011
28	3	0.0106	0	0
Others	69	0.2446	663	0.6914
Total:	282	1	959	1

In figure 12, a scatter plot shows the relation between the percentage of protuses (P3) and warranty claims (P4).

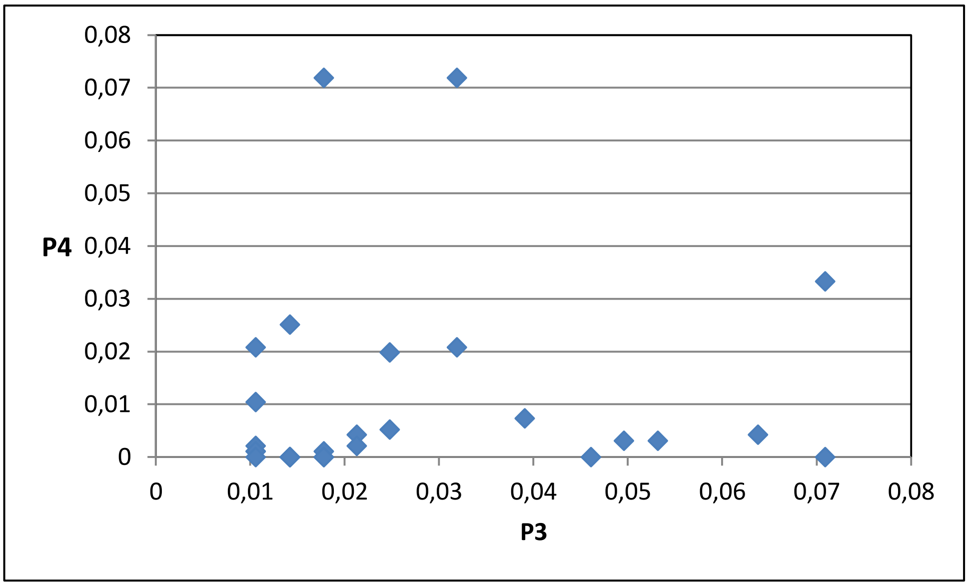


Figure 12: Scatter plot on the percentages (P3) and (P4), FH facelift project

Conclusion: From this second step it is clear that the amount of protuses does not correlate to the amount of warranty claims.

By regarding the two analyses and the conclusions from them, no correlation between the amount of protuses and warranty claims was observed. However the colored lines in the two tables illustrate that there are 7 parts that are common between the two tables. It is also presented visually that the 7 parts are not distributed in a similar way in the two tables.

In the specified time period there are 866 vehicles in service that have generated 959 warranty claims, as presented in table 3. There are 17262 vehicles that have been sold and delivered to end customers, which means that 5% of them have at some time had a failing part. The failure rate is 1.107 fault/vehicle (for vehicles in service that have reported claims).

Table 3: Summary of vehicles and claims, FH facelift project

Number of filed claims	Number of trucks	Total amount of claims
3	12	36
2	69	138
1	785	785
Total:	866	959

Figure 13 illustrates the distribution of warranty claims based on the number of months the vehicle has been in service. As figure 13 shows the amount of warranty claims are significantly higher in the first months of service. However the data presents claims of vehicles that have not yet been taken into service; these are labeled with 0 months in service. These claims are included and taken under consideration since the truck has been delivered to the retailer but not yet been sold to end customer. These claims might be indications of early life, assembly or logistics problems, such as scratched bumpers damaged by transportation.

There is a small amount of warranty claims registered to the 13th month of service, these are probably known faults and are therefore covered by Volvos goodwill.

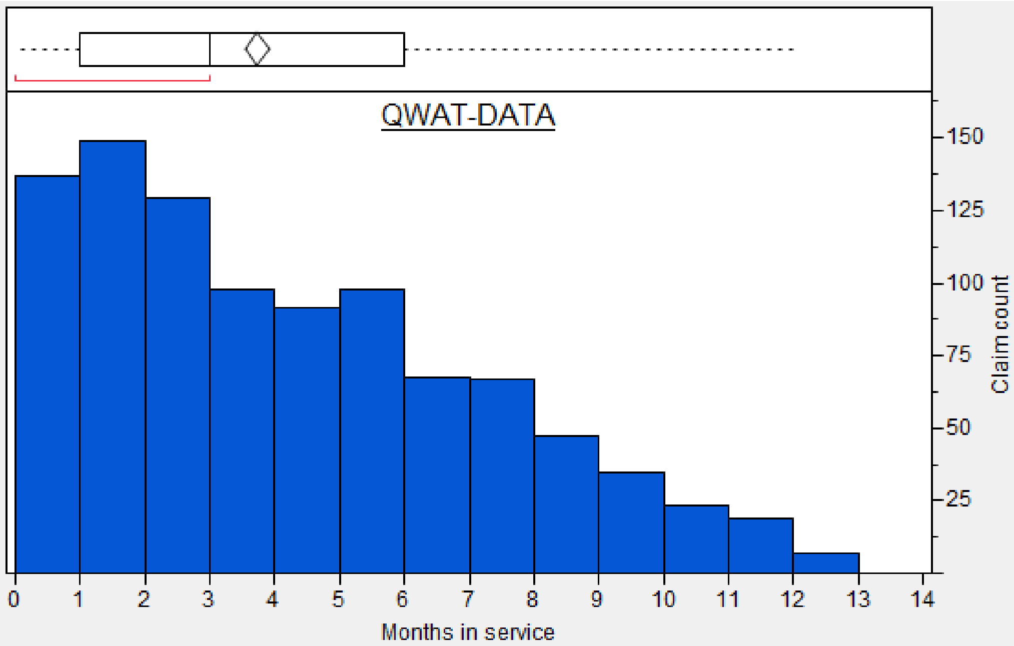


Figure 13: Distribution of claims vs. months in service, FH facelift project

Figure 14 shows the distribution of distance (km) to failure for each customer warranty claim and vehicle. It is evident that the majority of errors occur early in the product life cycle i.e. after a short accumulated distance. However there is also a truck that can be considered to be an outlier since its distance to failure is well beyond the average, this vehicle is marked with a red ring in the figure. As presented in the figure below a vast majority of failure occurs between 0 and 10000 km.

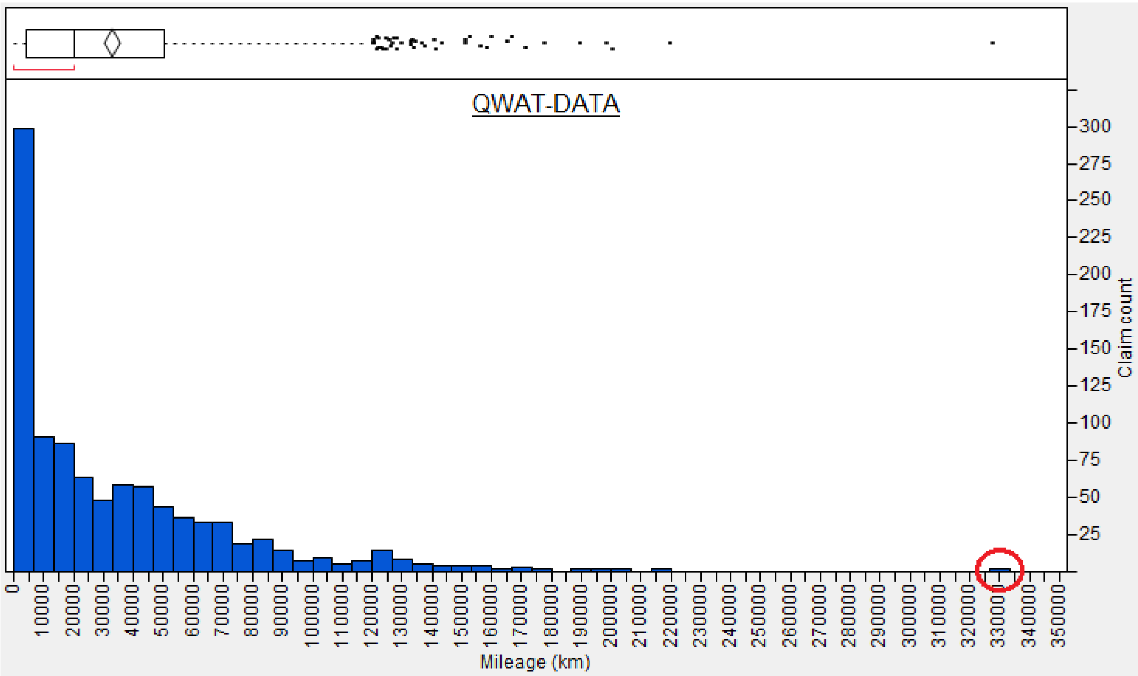


Figure 14: Claim mileage distribution, FH facelift project

By excluding the outliers and redrawing the distribution it is more evident that most customer warranty claims occurs early in the product life, see figure 15. It is 30% of all registered customer warranty claims that occurs between 0 and 5000 km. By further analyzing this subset of vehicles it is observed that 46% of the claims are connected to vehicles that have not been taken in to service (claim month 0). Further, this means that almost half of the first column, marked with a red interrupted line, should be excluded in order to illustrate the right distribution on mileage to failure.

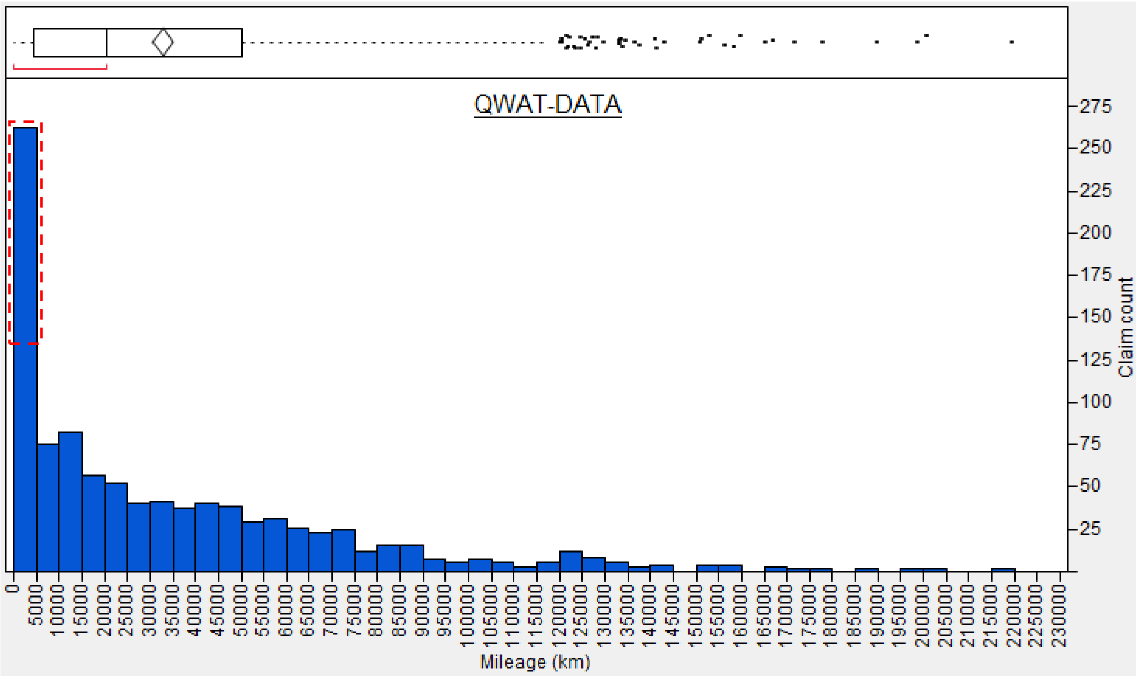


Figure 15: Claim mileage distribution, FH facelift project

When combining the two analyses above, the relationship between distance to failure and months in service is presented as a scatter plot, see figure 16. As illustrated in the figure below there is a relationship between mileage to failure and months in service. While the mileage increases with the months passed, the number of claims is instead decreasing. The vehicle marked with a red ring can be considered as an outlier.

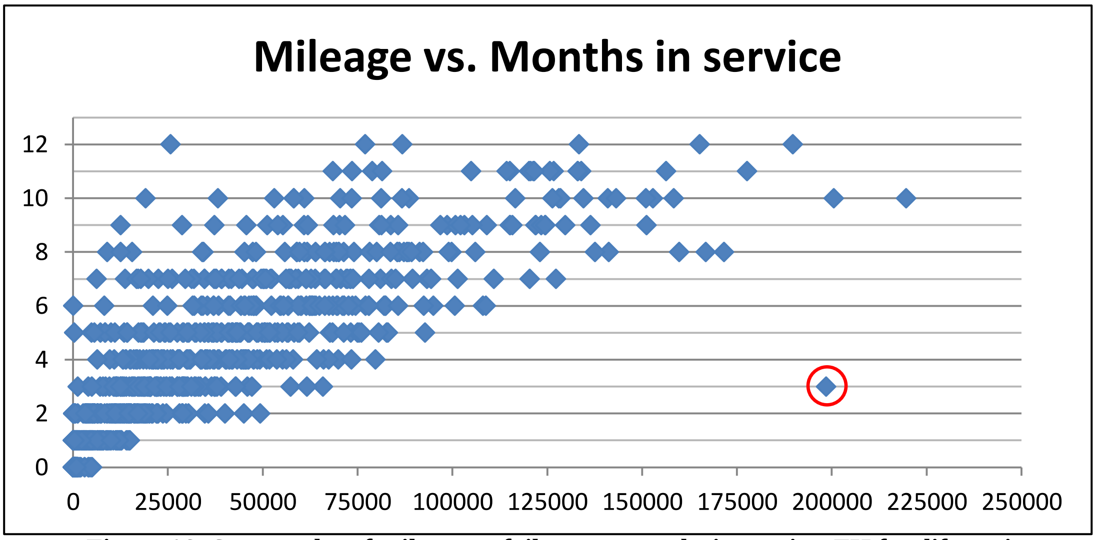


Figure 16: Scatter plot of mileage to failure vs. months in service, FH facelift project

By analyzing customer warranty claims by vehicle assembly date, as presented in figure 17, it is clearly illustrated that the early produced vehicles generate more warranty claims. This result indicates early life problems, most likely production and logistics related. However it is possible that the problems are related to known errors from testing that have not been solved until after production start. Further this warranty data has to be connected with the production data presented in figure 18.

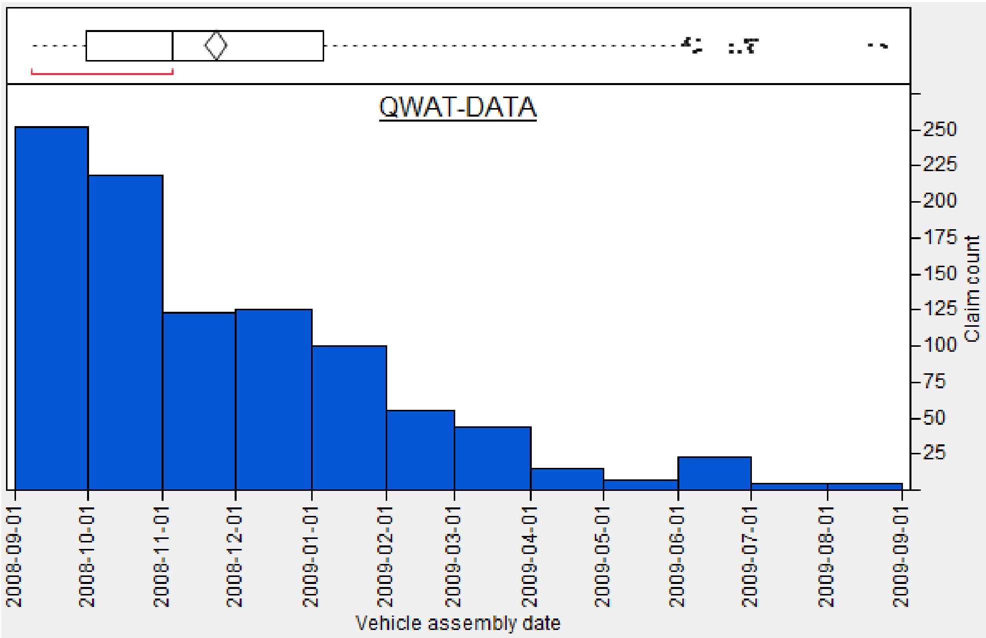


Figure 17: Distribution by vehicle assembly date, FH facelift project

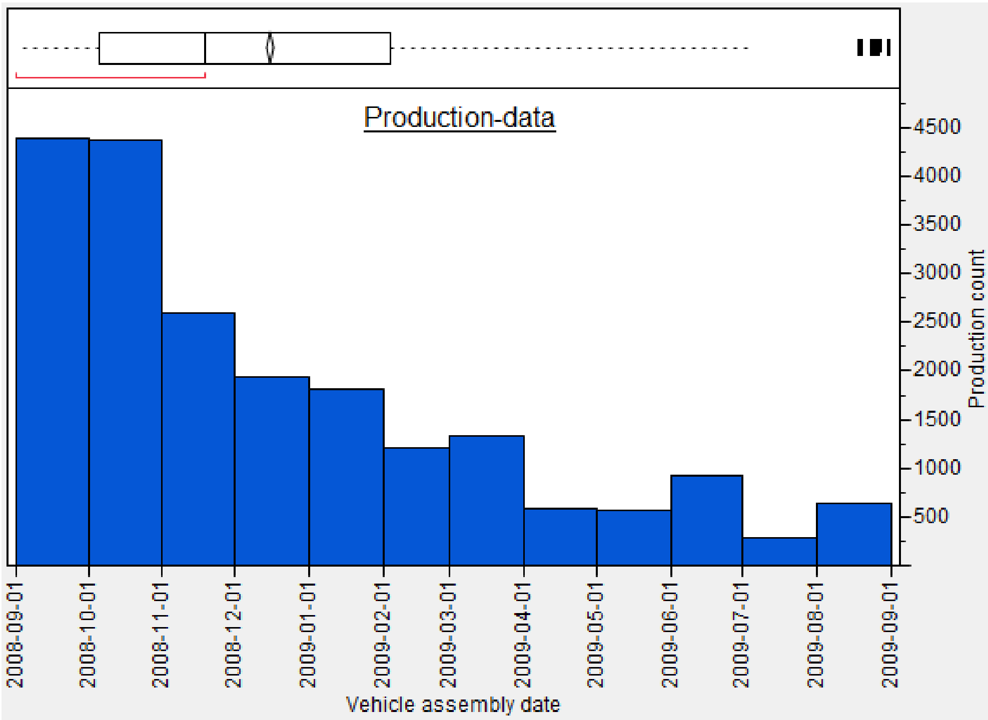
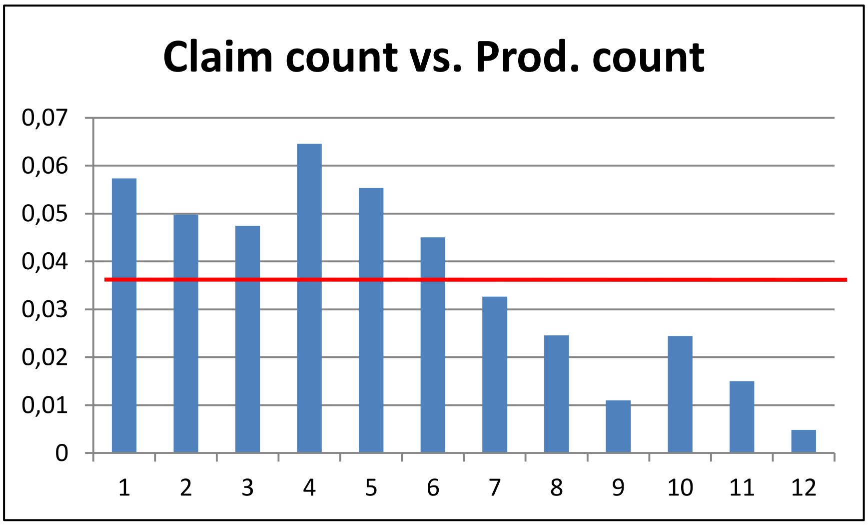


Figure 18: Number of vehicles produced over one year, FH facelift project

The ratio between customer warranty claims and the total amount of produced vehicles over a 12 month period is presented in figure 19. This is further proof that the early produced vehicles generates more warranty claims. The redline presents the average of 3.6% claims/produced vehicle.



Month	Percentage
1	0.057
2	0.049
3	0.047
4	0.064
5	0.055
6	0.045
7	0.032
8	0.024
9	0.011
10	0.024
11	0.015
12	0.005
Average	0.036

Figure 19: Percentage of claims on produced vehicles over a year, FH facelift project

4.2 Analysis of the FMX project (P2822)

The two data sets that will serve as the input for this analysis will incorporate information about part numbers, months in service, mileage to failure, vehicle assembly date etc. and for the FMX project (P2822) the warranty claims data is collected from September 2009 until September 2010, on FH/FM trucks before production start of the FMX truck. The Internal testing data is not limited by any timeframe but instead limited to the project scope of the FMX. It is evident that when looking at the warranty claims data for the FH/FM trucks there is one part that is a dominant contributor, see figure 20. The part stands for 87 percent of the total amount of claims for the period from September 2009 to September 2010.

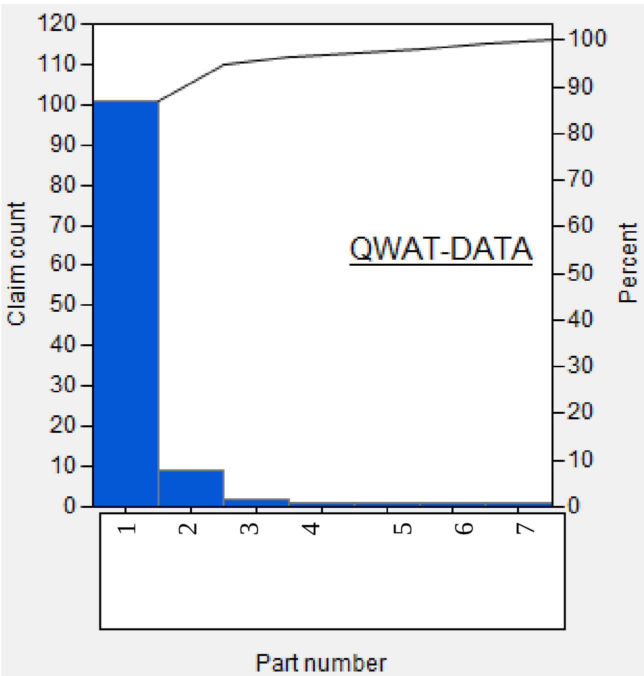


Figure 20: Claims by part number, FMX project

Table 4 shows the parts with the highest amount of protuses versus the amount of warranty claims for the same parts. By using the Pareto principle, 15 parts stands for 80 % of all the protuses written in the project, this however correlates to only one warranty claim in the period of September 2009 to September 2010. Table 5 shows the parts with the highest amounts of claims versus the amount of protuses, in a corresponding way. As the table shows only 4 parts that have warranty claims have protuses written on them. It is significant that only one part is common to the tables and hence, there seems to be no correlation at all between the testing data and the warranty claims for the new and modified parts in the FMX project (P2822).

Table 4: The highest contributing parts to customer warranty claims, FMX project

Part No.	No. L Protuses	Percent (P5)	Accu. Perc.	No. Claims	Percent (P6)
1	24	0.15	0.15	0	0
2	17	0.1062	0.2562	0	0
3	14	0.0875	0.3437	0	0
4	11	0.0687	0.4124	0	0
5	9	0.0562	0.4686	0	0
6	8	0.05	0.5186	0	0
7	8	0.05	0.5686	0	0
8	6	0.0375	0.6061	0	0
9	6	0.0375	0.6436	0	0
10	5	0.0313	0.6749	0	0
11	5	0.0313	0.7062	0	0
12	5	0.0313	0.7375	0	0
13	4	0.025	0.7625	0	0
14	4	0.025	0.7875	1	0.0086
15	4	0.025	0.8125	0	0
Others	30	0.1875	1	115	0.9914
Total:	160	1	1	116	1

Table 5: The highest contributing parts to L protuses, FMX project

Part No.	No. Claims	Percent (P7)	Accu. Perc.	No. L Protuses	Percent (P8)
1	101	0.8707	0,8707	1	0.0062
2	9	0.0776	0,9483	1	0.0062
3	2	0.0173	0,9656	0	0
4	1	0.0086	0,9742	0	0
5	1	0.0086	0,9828	1	0.0062
6	1	0.0086	0,9914	0	0
7	1	0.0086	1	4	0.0025
Others	0	0	1	153	0.9564
Total:	116	1	1	160	1

The scatter plot presented in figure 21 clearly illustrates that there is no correlation between number of claims and protuses.

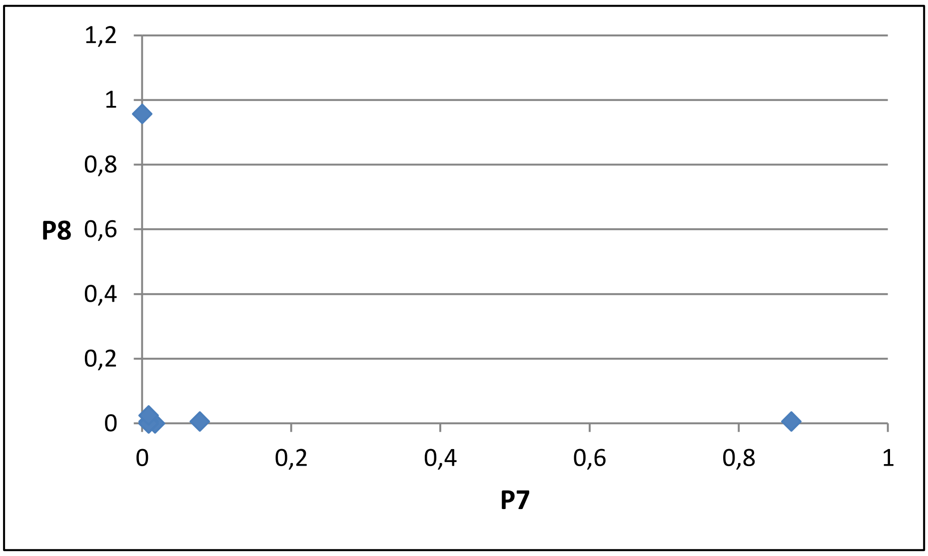


Figure 21: Scatter plot on the percentages (P7) and (P8), FMX project

Conclusion: From the presented analysis it is impossible to draw any conclusion about the amount of protuses having any correlation to the amount of warranty claims.

Over the time period there are 110 vehicles in service that have generated the 116 warranty claims, as presented in table 6. There are 15806 vehicles that have been taken into service, giving that 0.7% of them at some time had a failing part. The failure rate of each vehicle in service is 0.73 fault/vehicle (for the vehicles in service that have reported claims).

Table 6: Summary of vehicles and claims, FMX project

Number of filed claims	Number of trucks	Total amount of claims
2	6	12
1	104	104
Total:	110	116

Figure 22 illustrates the distribution of warranty claims based on the amount of months the vehicles have been in service. It is clear that only a few claims are filed under month 0, these being the trucks having not yet been delivered to end customer. These claims are included and taken under consideration since the truck has been delivered to the retailer and can be connected to early life, assembly or logistics problems. The graph also shows that the number of claims decreases with the number of months in service, but not continuously.

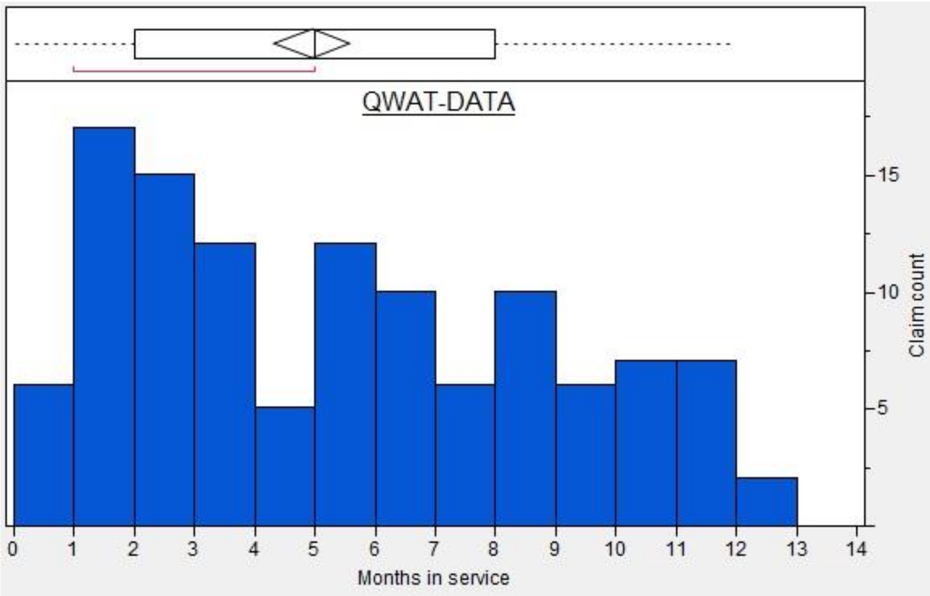


Figure 22: Distribution of claims vs. months in service, FMX project

Figure 23 shows the relation between distance to failure (km) for each vehicle and customer warranty claim. It is clear that the majority of errors occur early in the product life cycle i.e. after a short accumulated distance. As presented in the figure below most of the failures occur between 0 and 10000 km.

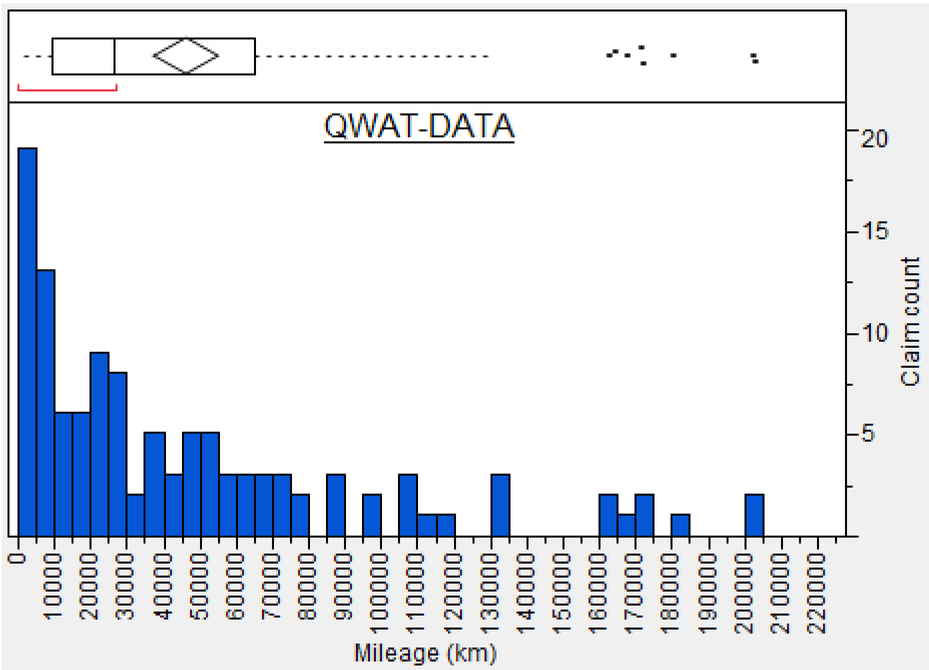


Figure 23: Relation between mileage to failure and amount of claims, FMX project

When further analyzing the relationship between distance to failure and months in service a scatter plot is used, see figure 24. As illustrated in the figure below there is a weak relationship between mileage to failure and months in service.

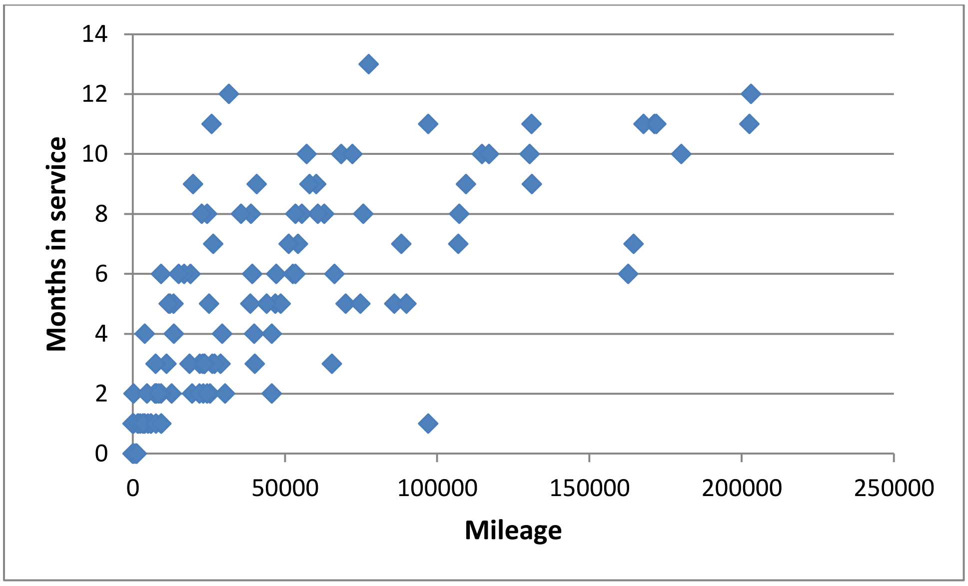


Figure 24: Scatter plot of mileage to failure vs. months in service, FMX project

Figure 25 presents distribution of customer warranty claims by vehicle assembly date and it clearly shows that the distribution is evenly distributed, except from one month where the warranty claims are significantly higher. These results are an indication of few early life problems and a good proactive work. When comparing this to the production data in figure 26 it is clear that this particular month had a busy production rate.

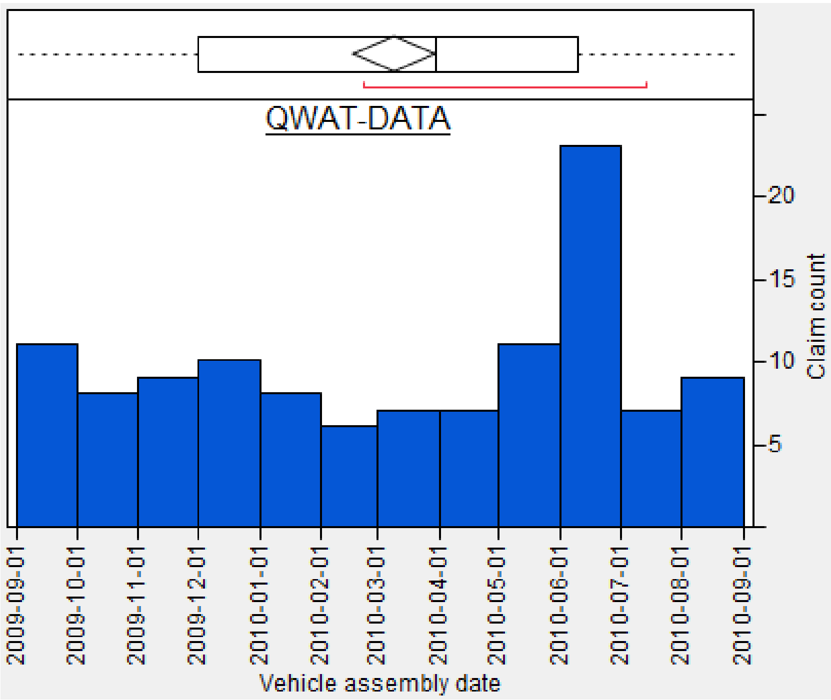


Figure 25: Distribution by vehicle assembly date, FMX project

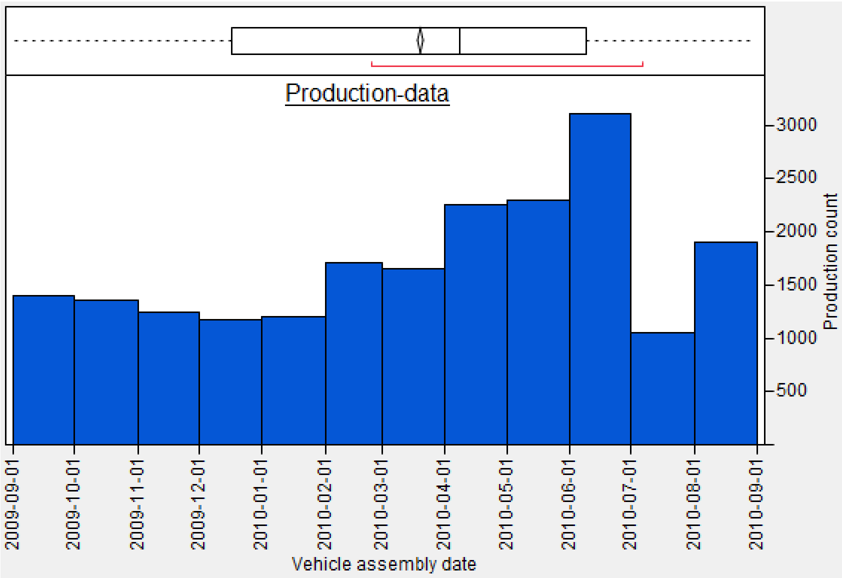
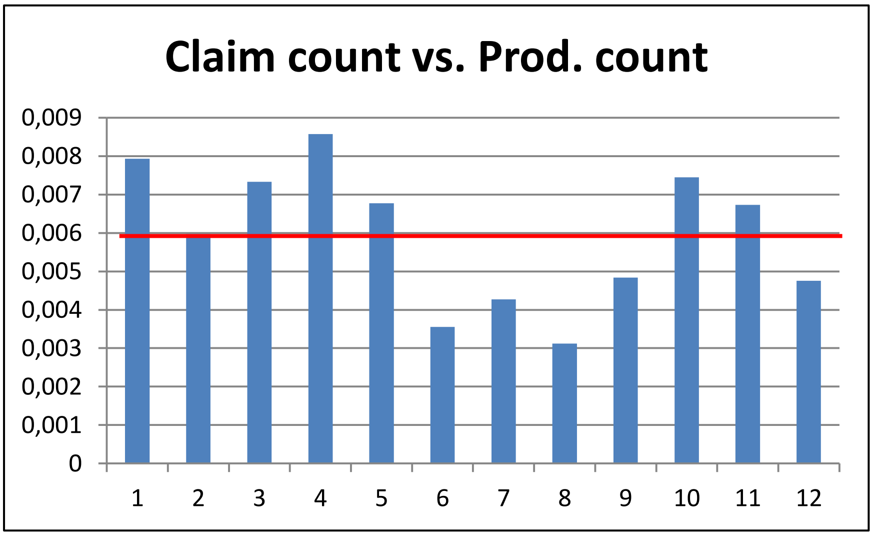


Figure 26: Distribution of vehicle assembly date, FMX project

The ratio of customer warranty claims over the total amount of produced vehicles over a 12 month period is presented in figure 27. When making this comparison it is evident that the month with the most claims does not have the worst ratio. It is instead shown that month 4 has the most claim/produced vehicle. The redline presents the average of 0.59 % claims/produced vehicle. This ratio is very low and to some extent confirms the fact that there is no obvious relation between protuses and customer warranty claims.



Month	Percentage
1	0.0079
2	0.0059
3	0.0073
4	0.0085
5	0.0067
6	0.0035
7	0.0042
8	0.0031
9	0.0048
10	0.0074
11	0.0067
12	0,0047
Average	0.0059

Figure 27: Percentage of claims on produced vehicles over a year, FMX project

5. DISCUSSION

The analysis conducted in this research shows that there is no correlation between test reports and warranty claims on new and modified parts in the two projects studied. However, it is impossible to draw any conclusions on a potential correlation between test reports and warranty claims in other projects that might be generalizable and be the basis for a future method to predict warranties.

An important notice is that even if the analysis shows no correlation, it could be argued that protuses that do not show up as claims is evidence of good and relevant testing in the development phase. This could also be termed as negative correlation where the claims from the field does not correlate to the fault reports in testing phase. Another important point with the negative correlation is that faults found in the testing are solved and could suggest that the testing should be extended so that the faults connected to warranty claims from the field can be found and prevented.

This research has included all protuses related to the two projects, however if a prediction method for warranty claims is to be created, it is necessary to sort out and include only the protuses related to reliability. The reason for this is the large amount of protuses unrelated to the reliability area, such as noise level, visual misalignments, durability problems etc. In order to create a model for prediction on these kinds of data, each protus report needs to be reviewed by an expert on the area to judge whether or not it is reliability-related. As Esterman et al. (2005) states, engineering judgment becomes as much of a data source as historical field data, product development testing data and failure assessment tools.

The same reasoning goes for the warranty claims data extracted from the QWAT database. Any valid attempts on creating a possible prediction model needs to take the different kinds of warranty claims into account to avoid a skewed prediction.

As already mentioned in chapter 2, the main problem related to reliability is that early in the development process there is little direct statistical evidence to predict reliability (Esterman, Gerst, Stiebitz, & Ishii, 2005). In connotation to this, although many reports present efforts on reliability prediction, few (if any) are attempting to make the specific relation between test reports and warranty data. Hence, this is a poorly explored area which amplifies the difficulty of finding a correlation.

The delimitations of this study inevitably leads us to the following question: Is it reasonable to do an analysis on *new parts only*? It is possible that a correlation would be more explicit if an analysis was made on all parts in the projects studied. An argument that speaks against this is the axiom that mature parts have least probability of faults, but this is hard to conclude without a comparable research where all parts are being considered.

Coit et al. (1986) highlights the typical statistical problems with databases, some of which were more prominent in this research. To start with, the homogeneity problem arises when determining which parts that have changed reference number or been modified and kept their old reference number. This adds substantial complexity to the task of extracting and selecting which parts that should be included in the analysis. Further, this complexity affects the certainty level of the analysis outcome and highlights the importance of selecting the right parts.

When considering the approach of this study, the problematic with working with parts and not groups of parts i.e. *function groups* must be noted. The parts in any complex machine, such as a truck, are interconnected and heavily dependent on each other which justify the categorization of parts into function groups that might be analyzed as a separate entity. Volvo engineers are usually working with function groups as opposed to parts and it seems logical to look at how parts in e.g. a headlight are affecting each other. In this particular context however, it must be noted that failure reports (protuses) are written on a part basis and they are the starting-point. This being said, it might still be easier to make viable correlations by working with function groups.

Another issue is the market mix problem. The problem is that components that are thoroughly tested might not be as heavily represented on the vehicles sold. A rain sensor can e.g. be tested in 70 % of all the test vehicles, but might be installed in only 10 % of the sold vehicles. This can result in a part getting a lot of protuses because of the heavy testing, but not at all as many warranty claims, because of the low presence on sold vehicles.

6. CONCLUSIONS

The original goal of this study was to explore any mathematical correlation between faults reported in the testing phase (protuses) versus the warranty claim data (QWAT). The ultimate purpose was (and is) to include the correlation in a simple and easy-to-use method for predicting warranty claims from test data only. Although an ambitious idea, it simply is not reachable for one thesis alone and therefore this exploratory study should be considered as a link in a long chain of research efforts with the goal of finding such a method.

The main concern is the amount of projects studied. It is dangerous to base predictions on a few projects, especially when each project is complex and depends on many different parameters e.g. temperature, vibration, humidity and usage wear (Coit, Dey, & Turkowski, 1986). For this reason, although no positive correlations were found in this research, the authors of this report do not take stance on the possibility of finding such correlation in other projects. On the other hand, the negative correlation, where protuses does not show up as claims, can be seen as proof of valid testing and problem solving. However, the opposite relation where claims in the field did not show up as protuses, implies that the testing either should be extended or redefined with a different focus.

What is certain is that several issues needs to be taken into account when analyzing further projects, regardless if the reason is to develop a prediction method or not. First of all, both protuses and claims need to be reviewed and sorted out depending on their consequence on reliability. Secondly, it is problematic to extract data from databases since part lists change frequently with e.g. parts being changed without getting new part numbers. Another issue questions if it is necessary to make this kind of research on part level, as opposed to function group level. This, because groups of parts affect each other and form dependencies while on the other hand, protuses are written on parts. Lastly, the market mix problem needs to be considered. A part can be over-represented during testing and hence provide misleading data.

All these aspects need to be taken into consideration when pursuing further analyses of the same type. Trying to predict the future, it turns out, is a complex task.

REFERENCES

Aldridge, D. S. (2006). Prediction of Potential Warranty Exposure and Life Distribution Based Upon Early Warranty Data. *IEEE*, 159-164.

Alsultanny, Y. (2010). Database Management and partitioning to improve database processing performance. *Journal of Database Marketing & Customer Strategy Management*, 271-276.

Andersson, J., & Lykken, P. (2006). *Correlation between complete vehicle testing and customer field result.* Gothenburg: Chalmers University of Technology.

Ansell, J. I., & Phillips, M. J. (1990). Practical Reliability Data Analysis. *Reliability Engineering and System Safety*, 337-356.

Bryman, A., & Bell, E. (2007). *Business Research Methods.* New York: Oxford University Press.

Coit, D. W., Dey, K. A., & Turkowski, W. E. (1986). Practical Reliability and Analysis. *Reliability Engineering*, 1-17.

Esterman, M., Gerst, P., Stiebitz, P. H., & Ishii, K. (2005). A Framework for Warranty Prediction During Product Development. *2005 ASME International Mechanical Engineering Congress and Exposition.* Orlando: ASME.

Freeman, J. M. (1995). Estimating Quality Costs. *The Journal of the Operational Research Society*, 675-686.

Kleyner, A., & Bender, M. (2003). Enhanced Reliability Prediction Method Based on Meeting Military Standards Approach with Manufacturer's Warranty Data. *Annual Reliability and Maintainability Symposium* (pp. 202-206). Kokomo: IEEE.

Kulinich, I., & Tufail, I. (2008). *Fault prediction method for product development (Implementation at Volvo 3P).* Gothenburg: University of Gothenburg, Department of physics.

Lu, L. Y., & Chiang, C.-C. (2008). Prediction Model for Warranty Costs: A Case Study of a LCD Monitor Company. *IEEE Asia-Pacific Services Computing Conference* (pp. 1418-1423). Chungli: IEEE Computer Society.

Mesbahul, A. M., & Suzuki, K. (2009). Lifetime Estimation Using Only Failure Information From Warranty Database. *IEEE Transactions On Reliability*, 573-582.

O'Connor, P. D. (2002). *Practical Reliability Engineering.* West Sussex: John Wiley & Sons.

The Volvo Group. (2011, 05 23). *Company Profile 3P*. Retrieved 05 23, 2011, from Volvo Group Global: http://www.volvogroup.com/group/global/en-gb/volvo%20group/our%20companies/volvo3p/Company_profile/Pages/Company_profile.aspx

Tufail, I. (2008). *Fault Prediction Method for Product Development - Analysis for designing and developing a fault prediction method.* Gothenburg: Chalmers University of Technology, Department of Technology and Economics.

Appendix 1

Interview: PROTUS management at Hällered proving ground

1. How and when is test reports (protuses) written?

2. Is it the same person that conducts the test and write the protuses?

3. Is there any prioritizing because of fault points?

4. Are protuses always written on already known faults i.e. parts that already have several protuses?

5. How is parts that fail during testing handled, are they changed immediately or are they changed when the test is finalized? (Assuming that the truck is still drivable)

6. How are parts that have no part number handled?

7. Is there anything that you think should be changed with the PROTUS system?