Understanding of a failure frequency peak in conjunction with a market introduction

How corporations can understand and foresee the impact of infant mortality

by

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Cover:
Illustration of failure frequency peak early after market release

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ABSTRACT

Successfully predicting field reliability of a new product before introducing it on the market decreases the risk connected to product development significantly. Being able to forecast the amount of complains that a product will encounter from customers in forehand, means that an organization in a better way can plan the resources needed both in the development of the product to reach the specified quality targets and in the future maintenance of the product. This thesis has investigated Volvo Group Trucks Technology's, a sub-division within Volvo Group henceforth referred to as GTT, ability to predict reliability for a new product in conjunction with a market introduction. With the help of reliability theory and a quantitative analysis of the received warranty claims for a specific product line the thesis performed a qualitative analysis of GTT's ability to predict the failure frequency for the trucks' first year on the market, by considering how GTT works with reliability prediction. Obviously, Volvo Group as a company will benefit the most of preventing the failures from occurring at all. Therefore the quantitative analysis of the warranty claims also aimed to provide as basis for future root-cause analysis to these failures, which is essential in a future initiative to preventing them from happen.

Early after its market introduction a new product often experiences child diseases. This shows as a peak when plotting the failure frequency for the product against time on market. Historically, when looking back on failure frequency data in conjunction with market releases, this trend can be seen at GTT as well. The initial period when this peak occurs is in this thesis referred to as the peak period. A majority of these failures are often connected to shortcomings in the manufacturing process, deviations from the intended usage of the product, misunderstandings of the customer requirements or failures in components delivered by suppliers. As long as these failure types exist, a product will not reach the intended reliability it's designed for. The reliability perceived by the customer is referred to as field reliability, which will not be equal to the design reliability for a new product until all quality issues related to these sources of variation are solved. When the product has reached this state the thesis refers to a stable condition or that the product is within the stable period.

GTT's methodology for predicting field reliability, proved to be accurate for the stable period but not being able to handle the initial peak period. In addition, the methodology proved to be capable of identifying trouble areas, which also reflected the analysis of the outcome of warranty claims. As the reliability growth testing within GTT mainly is focused on development failures and the variation connected to the market introduction is hard to simulate, GTT intentionally with the help of their reliability growth model only predict failures related to design reliability. Instead the predictions within the initial peak period are adjusted with a peak factor that is intended to compensate for the variation causing the discrepancies between the design reliability and the field reliability.

It can be concluded that the peak factor not is capable of compensate for the variation during the peak period. The authors identified various factors, which most likely affect the magnitude of the peak that is not taken into account when estimating the peak factor. These factors together with improvements in managing the failure frequency peak are further discussed in the thesis. Due to the time limit the magnitude of these factors' impact was not evaluated, but will be in GTT's interest to further investigate in future work of improving the ability to predict the reliability during the peak period and the management of the failure frequency peak.

Keywords: Quality, Reliability, Predicting Reliability, Field reliability, Warranty claims, Reliability Growth Model, Market introduction, Failure frequency, failure frequency peak

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Prediction is very difficult, especially about the future.

—Niels Bohr

LIST OF ABBREVIATIONS

FF – Failure Frequency

GPQL – Global Project Quality Leader

GTT – Group Trucks Technology

ITI – International TechneGroup Incorporated

MIS – Months in Service

PMQ – Project Manager Quality

PQL – Project Quality Leader

RG – Reliability Growth

RGM – Reliability Growth Model

RPM – Reliability Process Management

SOP –Start of Production

QJ – Quality Journal

Q&CS – Quality and Customer Satisfaction

QA – Quality Action

1 INTRODUCTION

The introduction aims to provide the reader with a brief understanding of the academic area of reliability, the purpose of the thesis and its relevance for the Volvo Group. In order to achieve this it will describe the background to the thesis and a short presentation of Volvo Group, introduce the concept of reliability and give a brief explanation of the idea behind reliability prediction. Further, it will describe the process behind the generation of the thesis' purpose and in the end present the research questions that will be answered in order to accomplish it.

1.1 BACKGROUND

Developing new products today involves high risk. The market environment gets tougher due to global competition and more demanding customers. As customers expect a better product than its precursor their expectations increase continuously. So to be competitive a company needs to understand their customers, in order to be able to develop a product that satisfies their needs (Balachandra, 1997). Not living up to these expectations can be crucial. A recent example of this is Boeing's Dreamliner project, which caused major unforeseen quality costs and additional development costs for the company. This was due to a product that not was able to live up to its requirements, in the end causing dissatisfying customers who not could traffic their newly acquired aircrafts (White, 2013 and Fontevecchia, 2013).

As the complexity of the product and its technology increase, so also will its development process. The challenges of developing a new product means that a corporation experiences a tensed period of time in conjunction with a market introduction. To ease the unawareness of a project's outcome it is valuable to be able to predict how well the final product will fulfill its requirements, or rather its risk of not fulfilling them also referred to as its rate of reliability. By monitoring the reliability growth (RG) within a development project and utilizing a Reliability Growth Model (RGM), a company has the possibility to predict the future reliability growth for the product and thereby in some means foresee how the product will live up to its requirements on the market. This allows the company to continuously distribute its resources on the most important issues, concerning the products reliability, during the development and by that ensure the expected reliability of the final product at the time for market introduction.

This Master's thesis has been conducted for Volvo Group in Gothenburg, Sweden to which most of the results refer, and has examined their ability to predict reliability for new developed products, before reaching the market introduction.

1.1.1 Volvo Group

Volvo Group is one of the world leaders in developing and manufacturing trucks and employs about 110.000 employees all over the world (Volvo Group, 2014). Volvo Group's vision is to become the world leader in sustainable transport solutions. Volvo Group's way of achieving this is expressed in four objectives, which are shown below;

- creating value for customers in selected segments
- pioneering products and services for the transport and infrastructure industries
- driving quality, safety and environmental care
- working with energy, passion and respect for the individual.

(Violin 1, 2014)

Volvo Group is a line organization with functional groups, as seen in Figure 1, working in collaboration to together reach Volvo Group's vision. The functional group that supports Volvo Group with research, engineering, product planning, purchasing and support on the aftermarket, so that the company can deliver complete vehicles together with aftermarket services (Violin 2, 2014), is GTT, which will be in focus in this thesis.

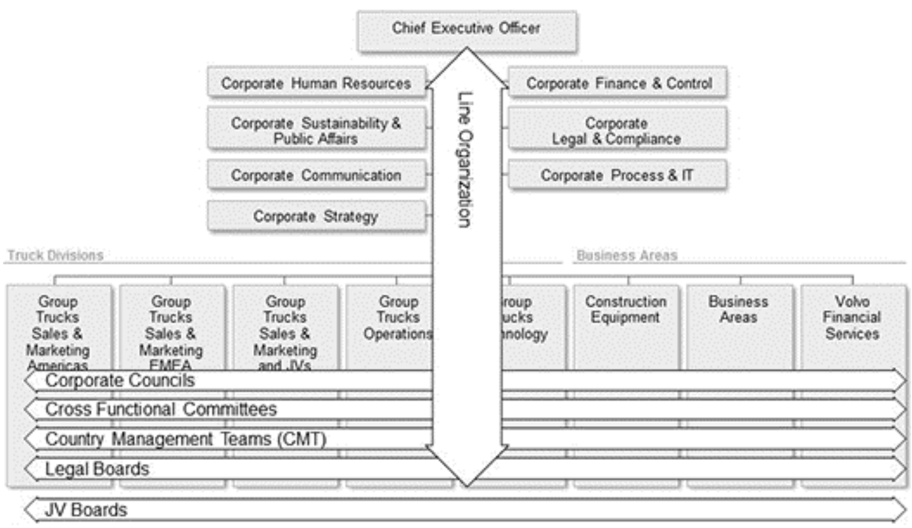


Figure 1. Volvo Group organization chart (Violin 1, 2014)

GTT's organization is, as seen in Figure 2, divided into functions that collaborate cross functionally. The company has two general processes for development of products, referred to as the project process and the maintenance process. The project process is used for development of new products and the maintenance process aims to continuously improving products, when needed, on the aftermarket. What the two processes have in common in terms of quality is that they aims to assure as high reliability for their end customer as possible, which is in line with Volvo Group's ambiguous target to be the most reliable truck on the market.

Within GTT, the section Quality and Customer Satisfaction (Q&CS) is responsible for ensuring that the products complies with the promised quality. Its mission is to *"Secure Volvo Group Trucks leadership in Customer Satisfaction"* and this will be achieved by "*Developing a culture committed to Quality Excellence and by driving efficient quality and safety processes and tools deployment*" (Violin 3, 2014).

The Q&CS organization is divided analogously to the general development processes, a project organization that is responsible for quality assurance for new development projects and a maintenance organization that works with assuring product quality after release on market by managing the maintenance process.

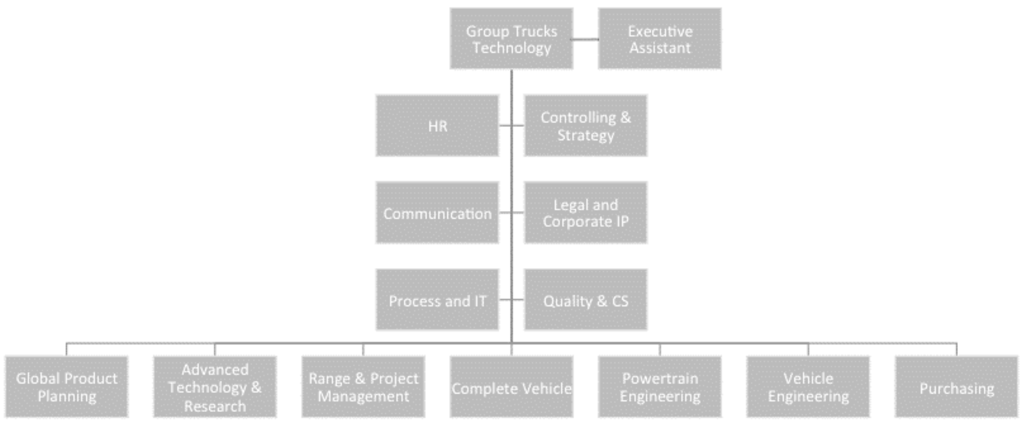


Figure 2, GTT organization chart (Violin 3, 2014)

This Master's thesis is an initiative from the maintenance organization at Q&CS who experienced that both organizations within Q&CS would benefit from a trans boundary investigation, focusing on their current ability to predict the reliability of new products prior to market introduction and the managing of the quality assurance in conjunction with it.

1.1.2 Quality and Reliability

Quality, safety and environmental care (Violin, 2012) are three key focus areas at Volvo Group. This thesis will primarily focus on the area of quality, it is therefore of interest to elaborate around the term in more detail. Quality is an old term with heritage from the Latin language (Bergman & Klefsjö, 2010) and has since then become a common term to express a product's or a service's performance. There are numerous definitions of quality but most of them are related to the customer's expectations of the product (Bergman & Klefsjö, 2010). This thesis has embraced the definition stated by Bergman and Klefsjö (2010, pp. 23) who uses a customer oriented definition, which is in line with Volvo Group's core values that also are customer focused.

"The quality of a product is its ability to satisfy, or preferably exceed, the needs and expectations of the customer"

Bergman and Klefsjö continues to unravel the concept of quality by presenting eight dimensions of quality for goods, namely; Reliability, performance, maintainability, environmental, appearance, flawlessness, safety and durability.

This thesis focuses on the dimension of reliability, which is one of Volvo Group's core competitive assets (Violin 4, 2014). O'Connor (2002, pp. 2) define reliability as

"The probability that an item will perform a required function without failure under stated conditions for a stated period of time"

He also states that it can be expressed as the number of failures over a period (O'Connor, 2002). This definition is more similar to how Bergman & Klefsjö's express reliability, which again uses a customer focused view, stating that reliability is a measure on how frequently a product experience problems and how the impacts of these problems affect the customer (Bergman & Klefsjö, 2010).

1.1.3 Failure Rate and the bathtub distribution

In accordance to O'Connor's (2002, pp. 2) way of expressing reliability, failure rate $\lambda(t)$ is a frequently used term for measuring reliability where λ is the probability that the product will fail during a period of time (t). For non-repairable products the failure rate curve usually take form as a U, hence it is commonly known as the bathtub curve, which is illustrated in Figure 3.

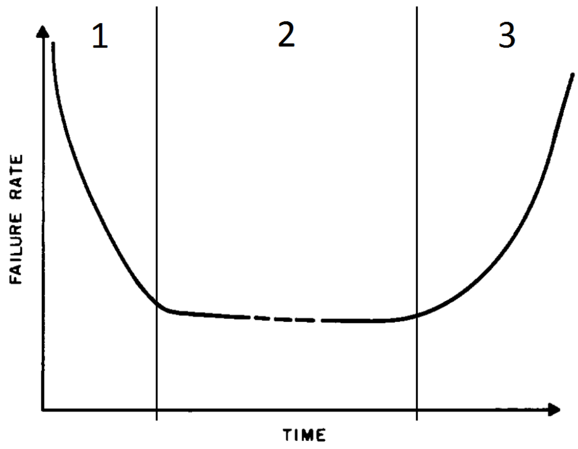


Figure 3, Bathtub curve (Kuo &Kuo, 1983)

The curve can be divided into three periods, the first period known as early failure period, the following period as the constant failure rate period and the third period as the wear-out period (Bergman & Klefsjö, 2010). The early failure period has a high failure rate and a steep slope, failures in this period is known as infant mortality failures or child diseases. This is often due to flaws in the manufacturing or due to deviations in the material, which causes the product to fail. This period can also be referred to as the burn in period (Kuo & Kuo, 1983). During the second period the failure rate is more or less constant at a certain level and the failures that occur are seen as random failures. In the third period, the wear-out period, the failure rate is increasing again, this is due to the product has aged and worn out and these type of failures are usually referred to as durability failures rather than reliability failures.

1.1.4 Predicting Reliability Growth

In accordance with the bathtub curve, a product often suffers from infant mortality when introduced on the market, which causes a high failure rate. These failures are usually corrected on forthcoming products when customer complaints are reported and the manufacturer gets aware of its wrong doings. When the failures are plotted on a time line it will take a similar shape to the first period of the bathtub curve. The speed of this continuous improvement is known as Reliability Growth (RG) and decides the slope of the plotted curve.

There exist a number of models that are able to predict the future reliability growth for a product, based on the product's historical reliability growth. These models are referred to as Reliability Growth Models (RGM). One of the better-known RGMs is the Duane model. Duane (1964) discovered that "several different and complex electromechanical and mechanical systems are shown to have remarkably similar rates of reliability improvement during system development”. When plotting the failure rate for different systems against the test time, the plots followed a relatively simple and predictable pattern, which significantly reminded of the well-known learning curve. Thereby, Duane draw the conclusion that it was possible to predict the reliability growth of a repairable system with the data gathered from the system’s historical failure data. The Duane model’s failure curve follows a logarithmic shape that becomes linear when drawn on a log-log scaled paper and thus can the curve easily be prolonged to predict the reliability (Duane, 1964). This concept can thereby be used to monitor the reliability growth during development projects and to predict the time required to reach a satisfactory level of reliability before introducing a new product on the market (Dhillon, 1980).

1.1.5 Reliability growth prediction within Volvo Group

At Volvo Group the RG takes place in accordance with the two general development processes, mentioned earlier. In the project process the RG is the outcome of the quality improvements connected to the continuous development testing that is performed during the development of a new truck. After the new truck is released on the market the RG is a result of the ongoing maintenance process, which monitors the product lines reliability through warranty claims and take actions through quality improvement projects when needed.

Instead of failure rate GTT uses Failure Frequency (FF) as a key reliability measurement. FF is the average number of received warranty claims for the trucks within a population for a specific time period. The trucks released on the market are divided into populations based on their assembly month. It is for these populations that the maintenance organization continuously monitor the FF values received from warranty claim data. The populations’ FF values are plotted with a regular time interval during the warranty period of the truck, mainly after three, six, nine and twelve Months in Service (MIS). These FFs are referred to as FF3, FF6, FF9 and FF12 respectively. As example, the FF12 value for January 2012 will not be available until January 2013, 12 months after the truck was sold.

FF12 is the key reliability indicator within Volvo Group and the value this thesis will focus on. A population’s FF value is accepted first when more than 65% of the population has reached the MIS connected to the specific FF value. This causes a delay in the monitoring of FF values, for instance can the FF12 value for a population sometimes not be available until 14 months after the particular assembly month, depending on if more than 65% of the trucks in that population has been used for at least 12 months or not.

Volvo Penta, a sub division in Volvo Group that primarily manufactures marine engines, was first to predict reliability during the development process with the use of ITI's RG model. 1998 they started to implement a software based on Duane's model with the help of a consultancy firm named ITI. Four years later Volvo Construction Equipment (VCE) started the work of implementing the same tool, which resulted in that the responsible received Volvo Group's internal quality award for their impressive work with RGM in 2008, and more specifically its ability to reduce the amount of warranty claims peak that normally occurs in conjunction with the market introduction for new products (Violin, 2013). In 2004 GTT also started to implement the tool and has since then been working more and more intensively with ITI's RG model.

2 DEFINING THE PROBLEM

This part will describe Q&CS initial problem and the thesis' problem definition, purpose and delimitations. It aims to give the reader a thorough understanding of the original problem in order to unravel why GTT has interest in the thesis being carried out. In addition, it will present the process behind the elaboration of the thesis' purpose.

2.1.1 Description and definition of problem

The problem was initially described in a startup meeting with key persons from the two organizations within Q&CS. The meeting exposed two possible tracks that seemed interesting to further investigate. Firstly, it was a common perception that it had been discrepancies between the predicted FF12 values received from ITI's RG model and the real FF12 values received from warranty claims. Secondly, a recurring peak for the FF12 values in conjunction with the market launch of a product could be identified in major historical projects.

In Figure 4 the two problem areas above are visualized for a typical project. In the left quadrant before SOP the RG for each development test phase within the project process is plotted. This is represented by the curve with fluctuations and corresponds to the amount of found failures within the each specific test phase. When issues are solved during a test phase the FF12 value decreases correspondingly, meaning that the FF12 value represent the numbers of unsolved failures that exist on the truck, that is expected to occur within 12 months of usage, at a time *t* during the development phase. Hence, the unsolved failures from a test phase follow to the next test phase and represent the start value of the FF value for that phase. The reliability growth is predicted from ITI's RG model for each test phase, represented by the exponential curves within each test phase. Before a truck is released on the market a last prediction is made which is handed over to the maintenance organization in terms of two values, the expected FF12 at SOP and the expected FF12 for the trucks assembled 12 months after SOP. These values are shown in the upper right quadrant, after SOP, together with the measured FF12 from warranty claims. Here, the discrepancies mentioned above are visualized as well as the peak that arise for the FF12 values from warranty claim data can be seen.

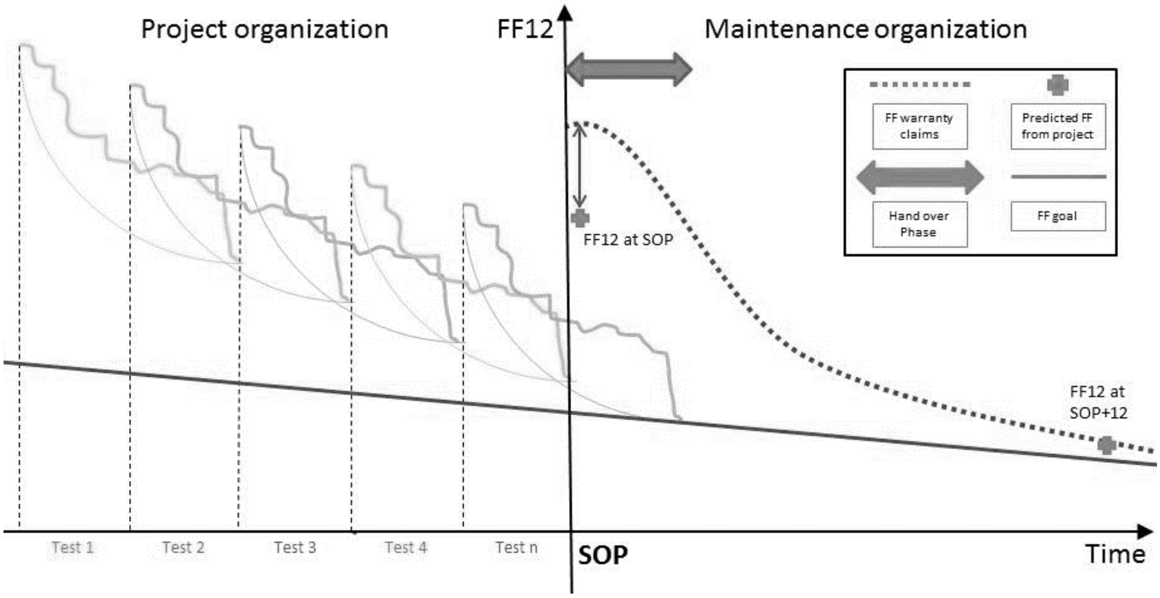


Figure 4, Description of the RGM phases and the Peak

To be able to get a better understanding of the problem and to find a suitable approach for the thesis the authors' acquired deeper knowledge about how GTT works with reliability growth predictions, their current initiatives for preventing the peak and reliability related theory in general. All this was carried out by an initial literature study on reliability growth prediction and reliability theory in general, together with unstructured interviews with stakeholders from the two organizations. The interviews were held with the aim to get a deeper understanding of three main areas:

- How the reliability management process, including reliability prediction, within the two general development processes looks like and how the responsibility of the quality assurance process is handed over from the project organization to the maintenance organization for a major project.
- What it is that has caused the perceived discrepancy between the predicted FF12 values and the real FF12 values received from warranty claims, during the New FH-series' first year on the market.
- What it is that is causing the recurring peak for the FF12 values that is perceived to arise in conjunction with the market introduction of major projects.

The interviews were held as unstructured interviews with open questions, adapted to the interviewees' role within the organization and respective process. This made it possible for the interviewees to explain their perspective of the peak, what their role was in the process and what value they get from the process without the authors affecting them or their answers in any directions, all to get an objective perspective of the problem. The interviews often lead to recommendations for new interviewees who were responsible for or had a better view of other parts of the process. The interview process stopped when stakeholders from all parts of the process had been interviewed and the authors' knowledge of the process was considered sufficient. Chapter 3 Method, describes the methodology used in the literature study and the situation assessment at GTT in more details. The outcome of the theoretical study is presented in chapter 4 Theory and the empirical study in chapter 5 Situation Assessment.

Finally, the findings from the literature study and the situation assessment were summarized and used as input in an adapted version of the Affinity Interrelationship Methodology (AIM), where the authors themselves fragmented the gathered information into concrete pieces of fact and performed the AIM based on their own retrieved perception, with the goal to define the problem thoroughly and formulate the thesis' purpose with connecting research questions.

RGM is mainly intended for use during the development of new products. The main idea is to monitor the RG for a product during its development and to be able to estimate the amount of work that still is needed to reach the final reliability target. Earlier, studies have been conducted at GTT investigating the model's validity during the project process (Le Douarin, 2009). Hence, it was of interest to investigate its validity for the maintenance organization. With other words, how valid is the last prediction that the maintenance organization receives compared to the real warranty claims and is the RGM theory applicable for the predicting the RG during the maintenance process. To be able to do this analysis, it seemed vital to in addition understand what type of issues that is causing the FF12 peak.

2.1.2 Purpose

This thesis will examine Group Trucks Technology's ability to predict the FF12 for a major project in conjunction with a market introduction.

This is achieved by answering the following research questions:

1. What types of failures are generating the new FH-series' FF12 peak and how are these failures causing discrepancies between the RGM prediction and the FF12 values?
2. How was Group Trucks Technology's ability to before start of production predict the reliability for the trucks, in the new FH-series, produced up to one year after start of production?

2.1.3 Delimitations

This thesis is performing a qualitative analysis of GTT's ability to predict the reliability, by understanding what type of failures the peak in a case project contains. The mathematical details in ITI's RG model and its appropriateness for GTT has been evaluated in an earlier Master thesis, with more focus on the work with the model within Q&CS's project organization. The scope of this thesis has instead been to have a maintenance approach, and evaluating the model against its ability to predict the actual failures that can be identified in a peak according to related reliability theory.

3 METHOD

The method presents the methodology used to fulfill the thesis' purpose and answer the related research questions. In addition, it will describe the methods used for defining the problem and the elaboration of the thesis' purpose, briefly described in chapter 2 Defining the problem, in more detail.

The authors' choose to use a case study design for the research. It is widely used in business research and some of the most successful studies on business management have used this design (Bryman and Bell, 2011). The research was intrinsic, meaning that the research primarily focused on describing how GTT manages reliability and due to its practices is able to successfully predict reliability and prevent the FF12 peak from occur. Hopefully, the results can be used in future researches together with data from other cases, aiming to draw more general conclusions.

The research used an abductive methodology, which can be seen as a combination of deductive and inductive theory where the two methodologies are used iteratively. The researchers identified symptoms in the organization and with the help of theory connected these symptoms to causes for the discrepancies and FF12 peak. These causes formed theories, which were investigated further leading to new possible causes and so to the iterative process continued until proper conclusions were elaborated.

3.1 GENERAL APPROACH

In order to answer the research questions the general approach, which can be seen as four sub-processes illustrated in Figure 5 was used.

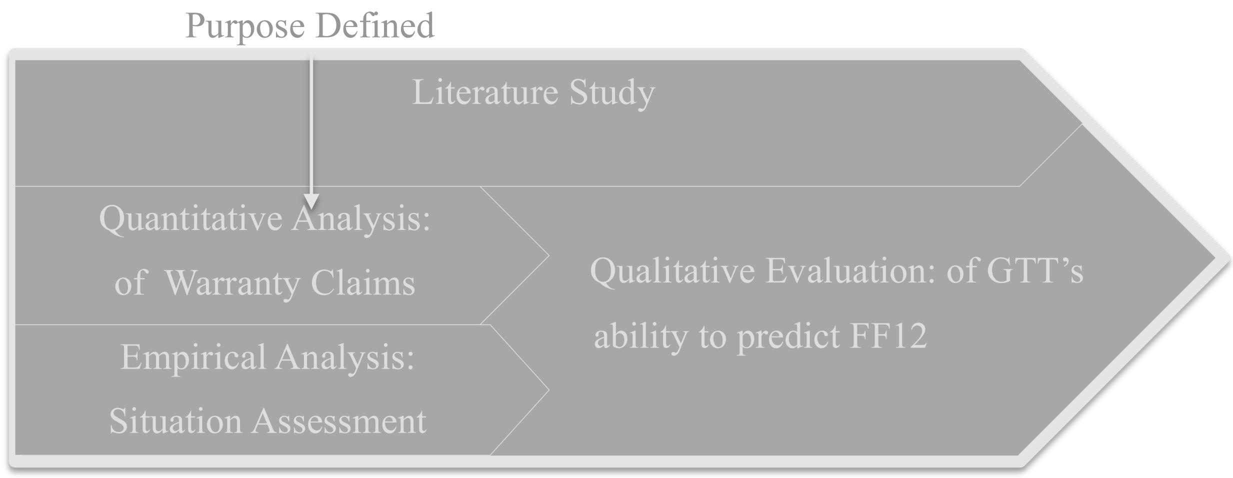


Figure 5, Illustration of the general approach used for answering the thesis' research questions

The three initiating processes started in parallel where the outcome of the two initial analysis provided as basis for the final qualitative evaluation of GTT's ability to predict reliability before reaching SOP, for trucks produced up to one year after SOP. By using the outcome of the quantitative analysis, identifying what type of failures that the FF12 peak existed of, the qualitative analysis considered the outcome of the empirical analysis, identifying GTT's methods for predicting reliability, to evaluate if GTT is capable of predicting the FF12 according to the theory.

This general approach was not self-explanatory, thus an abductive methodology was chosen as mentioned earlier. As described in Chapter 2 Problem Definition, the authors initially stood before an undefined problem with certain, by the company, perceived problem areas. Along the project, the authors were able to define the problem in accordance with the findings from the three initiating processes mentioned above. In parallel a clear purpose of the thesis was elaborated and a suitable approach for answering the connected research questions was shaped. Hence, the purpose was defined within the three ongoing initiating processes as seen in Figure 5.

In the following parts, the methodologies used within the four sub-processes are described in more detail.

3.1.1 Literature Study: Theoretical framework

Due to the abductive methodology, the literature study was a continuously ongoing process throughout the project. Overall, it can be seen as two general phases where the former was intended to give the authors a broader knowledge regarding reliability theory in general with a focus on reliability prediction. The latter, supported the qualitative evaluation of GTT's ability to predict FF12, but also considered how GTT can utilize their model for reliability growth predictions in a better way and better manage the reliability growth within the company in general.

The main source of information for the literature study was Chalmers library's databases such as Institute of Electrical and Electronics Engineers (IEEE) and earlier thesis executed on Volvo Group regarding RGM. Key words within the search have been: reliability management, bathtub curve, learning curve, predicting reliability, reliability growth prediction, reliability engineering and reliability growth model.

3.1.2 Empirical Analysis: Situation Assessment

The empirical study was carried out to get a good understanding of GTT's internal processes for reliability management and prediction, together with the concerned employees' perspective on the problem areas. The sources of information consisted of two segments namely; internal documentation and interviews.

Internal documentation was primarily carried out to understand GTT's internal processes for reliability management and prediction. Former Master Theses conducted at GTT on the same topic were initially used to give the authors a good overview of GTT's present work with ITI's RG model. When relevant processes and sections of GTT were identified the authors proceeded to gather more detailed descriptions in Volvos internal information library, Violin. Internal information from organizations can often be biased (Bryman and Bell, 2011), thus to make sure that the descriptions are valid the authors asked about the working procedure during interviews.

The interviews were conducted unstructured with pre decided topics that the interviewee could talk openly about. The topics were adjusted both depending on what position the interviewee had within the organization and due to that the authors received new knowledge from each interview, which would awake the authors' curiosity for a new topic. Firstly, the interviews intended to give a good overview of the involved processes and a deeper insight in the practical way of working with reliability at GTT. Later, the attention changed to different perspectives of the reasons behind the peak's occurrence, how reliable the FF12 predictions were perceived and possible explanations of the perceived discrepancies.

Roles of Interviewees	Interview Type
Project Manager Quality	Unstructured
Quality Range Manager	Unstructured
Project Manager Quality	Unstructured
Technology Specialist Reliability/Global Feature Leader Reliability	Unstructured
Global Product Quality Leader	Unstructured
Project Manager	Unstructured
Project Manager	Unstructured
QAG Manager	Unstructured
Quality Director	Unstructured
Product Safety Director	Unstructured
Product Quality Leader	Unstructured
Project Manager Quality	Unstructured

Figure 6, List of conducted interviews

3.1.3 Quantitative Analysis: Analysis of warranty claims

This part of the analysis aims to describe what type of claims that builds up the peak that occurred in conjunction with the market introduction of the New FH-series and to quantitatively evaluate the reliability predictions made within the project.

The authors had access to confidential data in the form of warranty claims reported in during the New FH-Series' service visits, all quality actions performed in Q&CS maintenance organization during the new FH-series' life cycle and failure frequency reports from older FH-series. These are all secondary data, collected by Volvo group, thus it needs to be complemented to fit this thesis analysis. It is common problem that secondary data are missing key variables (Bryman and Bell, 2011) and therefore it is of importance that the authors comprehend the data before starting to analyze.

The warranty claims for the New FH-series were assembled between October-2012 and May-2014.

3.1.4 Qualitative Analysis: Evaluation of GTT's ability to predict FF12 before reaching SOP

This part of the analysis aims to evaluate GTT's ability to predict FF12 before reaching SOP. It combined the findings from the three initiating processes, in order to qualitatively analyze GTT's ability to predict reliability before reaching SOP with respect to what causing the FF peak, how GTT predicts reliability, what the outcome of the predictions within the case project was and the theoretical framework.

3.2 CLASSICAL QUALITY CRITERIA

3.2.1.1 Validity

For a research to be able to reach a high validity is it of necessity to be open with where the content in the report comes from. The readers of a thesis must be able to review the literature and the data collection that builds up the analysis so that the conclusions drawn are supported by relevant data (Bryman & Bell, 2010). To increase the conformability and the credibility in the literature research phase the researchers in this report have based the conclusions on facts from acknowledged authors and keep their own opinions to a minimum. This report have used confidential data from Volvo groups warranty database and needed thereby to find ways to increase the validity without revealing any confidential data. The writers had a continuous dialog with the handler at Q&CS regarding the subject to be able to be as open as possible with the empirical phase in the report. The conclusions drawn from the analysis phase have been done in a way so that it is clear what facts these conclusions are based upon. The report have aimed to separate specific recommendations to Volvo Group and research generated results regarding in which environments and circumstances the models are appropriate, this will increase the transferability and make the report more useful for external readers.

3.2.1.2 Replication

A research needs to be replicable so that other researchers can perform the same study again (Bryman & Bell, 2010). This research describes the methodology and the way the research has been executed in detail to ease for others to replicate it. But it is still important to have access to data from the company to be able to replicate this study in order to verify the results for Volvo Group.

3.2.1.3 Reliability

Reliability concerns how stable the measures made in a research are (Bryman & Bell, 2010). This research uses both primary data and secondary data, the secondary data is primarily claims that are reported at Volvo Group's service stations thus was this data seen as keeping high reliability. The primary data is to a large extent from interviews, which are listed in Figure 6. The position of the interviewee will be stated so that other researchers can interview similar candidates. A large share of the secondary data that is used is, as mentioned earlier, confidential.

4 THEORETICAL FRAMEWORK

The theoretical framework is a result of the performed literature study and was used within the qualitative evaluation of GTT's ability to predict reliability for the trucks, before SOP. Initially, different notions of product reliability are presented from a theoretical point of view. This follows by an explanation of how the view on quality improvements from an economical perspective has changed through history. Finally, the concept of Reliability Growth is introduced together with methodologies for predicting reliability growth, focusing on the methodology used within GTT.

4.1 DIFFERENT NOTIONS OF PRODUCT RELIABILITY

In the background, the definition of reliability from Bergman and Klefsjö (2010) was presented. The concept of reliability is related to a product's ability to meet its requirements, however Prabhakar Murthy et. al. (2008) highlights the vague characteristics of the concept. A product's expected requirements will understandably differ from customer to customer and within a product's life cycle, between the design of the product and the end use at the customer, there is a lot of room for variance that will influence how well the product in the end is perceived to fulfill these requirements. Thus, in literature often a distinction is made between the "Design reliability" and "Field reliability" or "Achieved Reliability" (Prabhakar Murthy et. al, 2008 ; Smith, 2007). Where the Design Reliability is the theoretical reliability of a product according to the design and its probability to fulfill the technical specifications set for the product. The Field or Achieved Reliability of a product, corresponds to the actual perceived reliability by the customers after using it, see Figure 7.

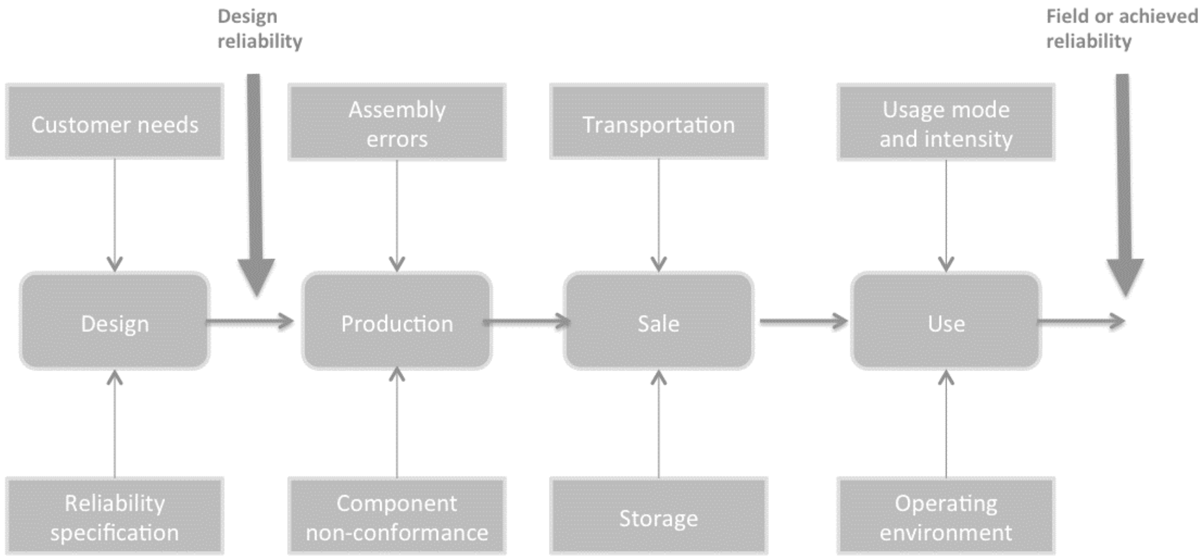


Figure 7, Visualization of design and field reliability (Adapted from Prabhakar Murthy et. al. 2008)

Design Reliability

The Design Reliability is seen as the maximal reliability that the product theoretically allows due to its design, reliability of ingoing components and the intended usage (Smith, 2007). It is commonly referred to as the expected reliability performance of the product at the end of the development phase, when all arisen quality issues has been solved and the product is performing according to its initial specifications and targets (Prabhakar Murthy et. al, 2008). When talking about reliability prediction, it is highly probable the Design Reliability that is in mind and the approach for predicting the Design Reliability is often based on field experience from similar products or parts (historical reliability data for each component), expert judgment and various types of simulations such as reliability block diagram or fault tree analysis (Prabhakar Murthy et. al, 2008).

Field or Achieved Reliability

Field or Achieved reliability is the actual perceived reliability by the customers themselves (Prabhakar Murthy et. al, 2008). This is an important distinction compared to the Design Reliability; since it means that if the Field Reliability should be equal to the Design Reliability it requires that the product is robust against all upcoming variance after the design/development phase in the product's life cycle (Smith, 2007), see Figure 7. This requires that the product is manufactured and works exactly according to the specifications and more important, that the customers is aware of the specifications and use the product in the way it is intended to work. The Field Reliability is calculated from available failure data, as in Volvo Group's case, warranty claims from customers (Prabhakar Murthy et. al, 2008). It is often lower than the Design Reliability due to varying environmental and operational conditions at the customers or variation within the production process (Prabhakar Murthy et. al, 2008). Therefore, the Design Reliability in some sense work as a target for the Field Reliability, which not is reached until the product's reliability is stable and no variation affecting the products reliability exists after the design phase in the product's life cycle.

When developing new complex products, the Field Reliability is hard to predict with the conventional methods, as discussed above used for predicting the Design Reliability, since the methodologies are all based on historical data or experience and therefore cannot handle the high degree of variance that occurs in the case of the new specific product.

In this case study, when talking about FF12 as a measure of reliability it is referring to the latter, Field Reliability. The FF12 values measured from warranty claim data is in this case the actual Field Reliability for the trucks. When discussing reliability in this report it is referred to the Field Reliability if nothing else is mentioned.

4.2 Economics of reliability

Feigenbaum (1956) was first with dividing the concept of Cost of Quality, generally acknowledged as the total cost of a products quality related deficiencies and efforts made to prevent these deficiencies, into the three segments:

- Failure Costs: cost due to insufficient quality such as defective materials or products that do not meet the quality specifications.
- Appraisal Costs: cost related to activities for maintaining the current products quality levels, inspection, quality control etc.
- Prevention Costs: cost related to proactive activities with the purpose of keeping defects from occurring in the first place.

Feigenbaum provoked that more attention should be given to preventive quality activities aimed to reduce the Failure Costs, which in turn logically also will reduce the Appraisal Costs since there is less need to control the quality. According to Feigenbaum, companies should in general allow for a higher Prevention Costs, in order to keep the Appraisal and Failure costs down. This reflection could be a plausible background for the theory about a quality "Cost Optimum" that according to Prabhakar Murthy et. al (2008) is frequently presented in textbooks and teaching on quality and reliability. The theory means that there is an optimum for the preventive quality actions and taking more actions then these will lead to a higher increase in Preventive Costs than the decrease in Failure and Appraisal Costs.

This mindset has with the years changed and is today considered as outdated. Today, the majority of companies, so also Volvo Group, have the same viewpoint as Deming (1988) presented in *Out of the Crisis*. Here he talks about Quality Cost for the first time as a complete waste, which on the long-term could be removed totally. He states that; "*there is no fundamental limit to the extent to which failures can be prevented. We can design and build forever-increasing reliability*." and that "*there is no point at which further improvement leads to higher costs*". Practically, this means that an initiative or activity for improving the quality of a product will be motivated independent of the cost for the activity in order to avoid the future costs connected to the failure of the product. He also describes an organization where these activities not are restricted to some kind of reliability function. Instead he believes that achieving a reliable product requires a totally integrated approach between all functions and in that case it is hard to separately identify and cost those activities that are specifically devoted to reliability.

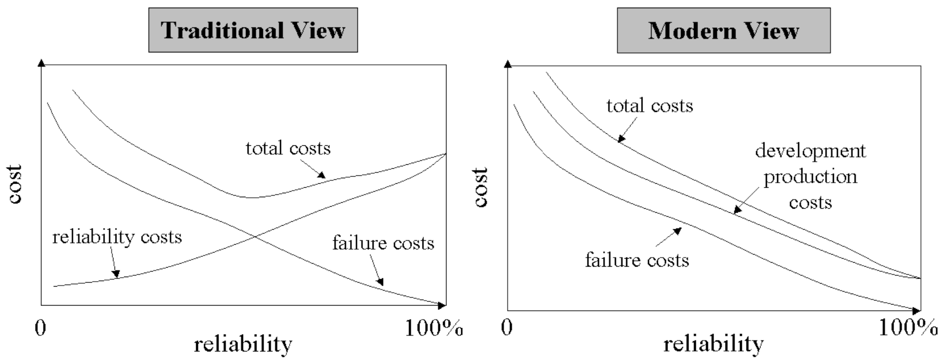


Figure 8, Traditional and modern view of cost optimization (O'Connor, 2002)

It is easy to draw parallels between this insight and the today's higher awareness of the indirect cost of quality, which would even strengthen the argument for aiming to reduce the failures completely. Indirect quality costs are unlike the direct costs not directly linked to the development and production of the product, but are instead dealing with costs related to warranty, extra transportation, administration costs, impact on product and business reputations which can lead to loss of sales and so on. Defoe (2001) highlights the large proportion of the quality costs that the indirect costs represents by comparing it with an iceberg, where the direct costs just represents the tip that is visible above the sea-level. He suggest that the direct costs consume 4-5 percent of the sales while the total cost of poor quality could represent as much as 15-25 percent of total operational costs.

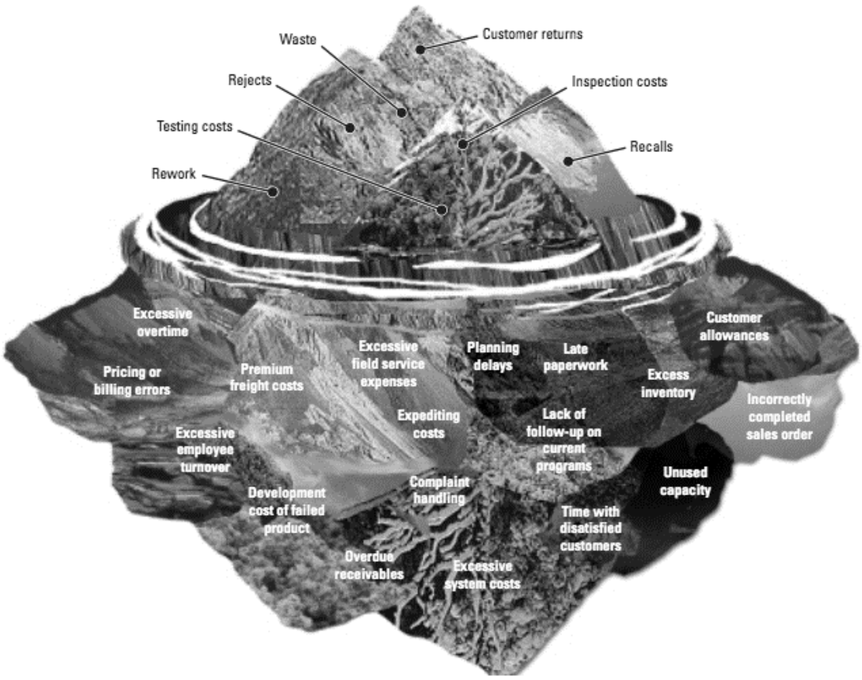


Figure 9, Cost of poor quality "tip of the ice berg" (DeFoe, 2001)

The high impact of the indirect costs can also be connected to the relationship between the relative costs of a design change against the time in a product's life cycle that Bergman and Klefsjö (2010) outlined. The indirect costs related to a failure can be considered to increase the latter the failure occur in the life cycle and the costs to implement the changes will according to Bergman and Klefsjö also be higher, which in some sense could be seen as indirect costs. The indirect costs will obvious also be higher the latter the failure occur, since the proportion of the phenomena related to the indirect costs will be higher, for instance the bad reputation of the product who will spread with time.

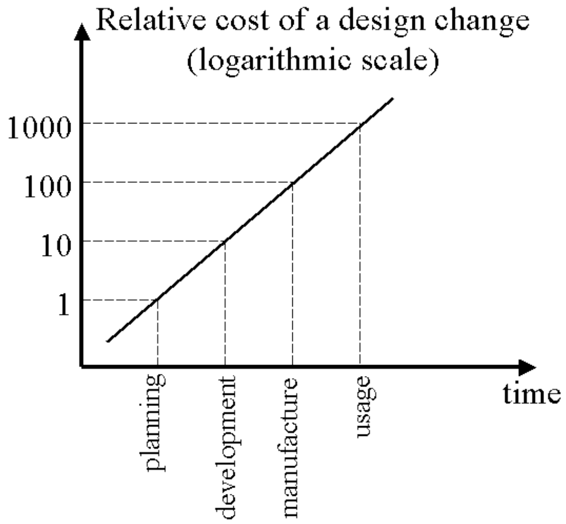


Figure 10, Cost against time (Bergman & Klefsjö, 2010)

4.3 RELIABILITY GROWTH MODELING

4.3.1 Reliability growth

According to Prabhakar Murthy et al. (2008) "*The objective of reliability growth testing is to improve the reliability of an item through minor design changes and changes in manufacturing processes and procedures.*" Intuitively a design does not at once work as intended, product development is therefore an iterative process, which requires verification of the design with following changes. In the verification process issues are identified who not corresponds to the requirements and necessary modifications are implemented, this type of working procedure is often referred to as reliability growth testing and as the quality issues are solved the products reliability increase. This is referred to as Reliability Growth (RG) and depending on where in the product's life cycle the variation, causing the quality issues arise, the Design Reliability or/and the Field Reliability increases (Prabhakar Murthy et al. 2008). If the variation existed in the design of the product the Design Reliability and the Field Reliability (stated that the design change not cause any further variation later in the product's life-cycle) grows. If it instead existed later in the life-cycle only the Field Reliability grows and reduces the gap between the Design Reliability and the Field Reliability. This is illustrated in Figure 11.

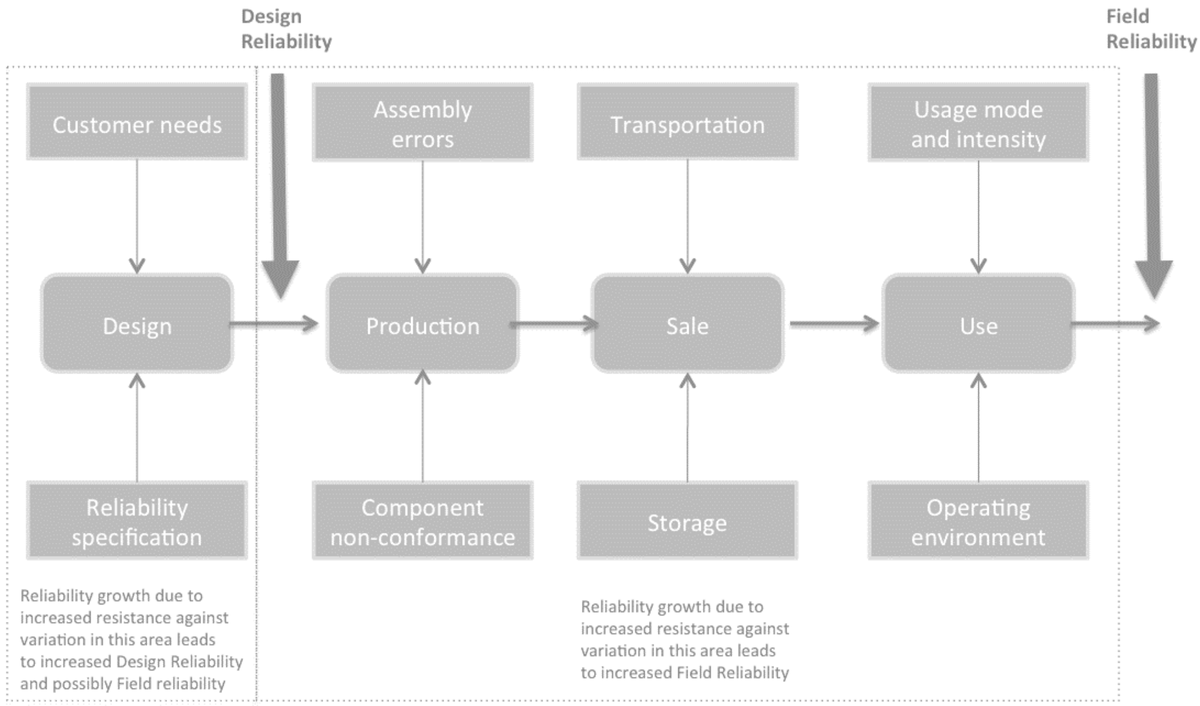


Figure 11, RG impact on product reliability depending on where the variation existed (Adapted from (Prabhakar Murthy et. al. 2008))

The reliability growth testing is often related to the latter part of the development process when the product is ready to be tested as a whole system; in this case the truck is being tested as a complete vehicle. This allows the performed tests to better correspond to the real usage environment, which is necessary for making the results more trustworthy. "*Reliability Growth… is the result of an iterative design process*" (Broemm, Ellner et al. 1999) and in literature this process often is referred to as a test, analyze and fix (TAAF) cycle (Prabhakar Murthy et al. 2008).

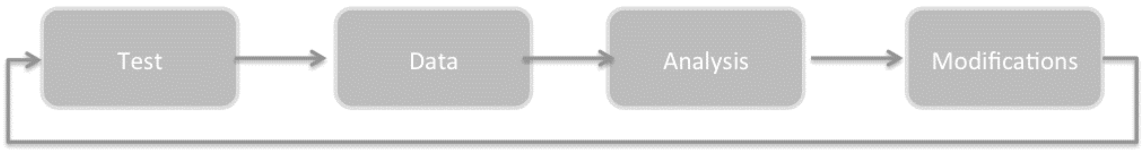


Figure 12, TAAF cycle (Adapted from Prabhakar Murthy et al. (2008))

In connection to a TAAF process O'Connor (2002) suggests that a FRACAS programme is used, which is an abbreviation for failure reporting, analysis and corrective action. In *Practical Reliability Engineering* (O'Connor, 2002) he provides a suggestion for how the FRACAS programme should be organized. Here he advises that a review board is set up in connection to the reliability growth testing, which task is to assessing failures, instigating and monitoring corrective actions and monitoring the reliability growth. He propose that the board should consist of:

- The project reliability engineer
- The designer
- Others who might be able to help with the solutions, such as the quality engineer, production or test engineer

O'Connor highlights the importance of the failure reporting process of the FRACAS programme, since the failure information can be valuable in several means. Besides from being used in the solving process for the issues, failures reported and stored digitally in a standardized procedure also can provide as input for future quality actions in the development process or within the maintenance process if a similar or related issue arise again.

4.3.2 Predicting Reliability Growth

An aspect that O'Connor (2002) did not mentioned about the FRACAS programme is that the information with reported failures, when used with a RGM, also provides possibilities for reliability growth prediction. According to Healy et al. (1997) predicting the reliability growth for a product under development allows following benefits:

- Performing trade-off studies between different designs
- Setting plans for continued developmental testing
- Planning for future design improvements
- Future cost studies for designs
- Providing basis for an evaluation of reliability growth
- Studies of future maintenance requirements

Unlike the conventional predictions method mentioned earlier who aimed to predict the Design Reliability based on the ingoing components' known historical reliability data, this approach for reliability prediction instead relies on test data from the current development project. Instead of considering each component's reliability individually, the whole product is seen as a system with a mutual RG. The RG can then be predicted due to that the RG during the development of the system tends to follow a certain pattern. In the case when Duane's Model is applied this pattern is the traditional learning curve, see 1.1.4 Predicting Reliability Growth for a more detailed explanation of the learning curve. It is important to consider that this method for predicting RG not by itself will reflect the Field Reliability of a product. To be able to predict the Field Reliability, the tests within the developmental testing must reflect all existing variation within the product's life cycle according to Figure 7.

The Duane Model is an exponential curve for which, the failure rate is decreasing exponentially with the growth rate G (reliability is growing as the failure rate is decreasing) with the cumulative time of the developmental testing. Below, see equation 1 (ITI, 2009), the relationship used in ITI's RG Model, the RGM used at GTT, is presented. This is an adapted version of the Duane Model where T_0 is added; T_0 is the time at when the first failure is identified in the current developmental testing period. This gives a more reliable result, since the improvement actions generating the reliability growth does not start until the first failure has been identified and reported.

$$\lambda = \lambda_0 \left(\frac{T}{T_0}\right)^{-G} \qquad \text{(Equation 1)}$$

Where:
$T =$ Cumulative Test Time, $T \geq T_0$
$T_0 =$ Growth Start Time, $T_0 > 0$
$\lambda =$ Failure Rate at Time T
$\lambda_0 =$ Starting Failure Rate at Time T_0
$G =$ Growth Rate , $G > 0$

With this relationship, when a FRACAS programme is implemented, the future RG can be predicted based on historical data collected from earlier development testing within the development project. The result of the prediction is plotted in a Growth Chart, showing how the failure rate is changing with time due to the developmental testing.

Below are the variables Growth Rate and Starting Failure Rate explained together with a listing of the factors affecting them (ITI, 2009).

Growth Rate, G

The Growth Rate is a value of how fast the reliability is growing in the development programme; with other words how effective the issue solving has been within the development testing. A higher Growth Rate means a more effective issue solving process, where the issues are solved faster and in a more effective way. Other affecting factors are:

- Resources and level of management priority to assigned to the reliability growth testing programme

- How rapidly test time is accumulated
- Ratio of failures to problems
- Amount of effort required to effectively solve problems

Reliability Starting point, λ_0

The Reliability Starting point defines what the current estimated reliability is for the product in the beginning of a development test phase or a future prediction. It points out the starting point for the Reliability Growth for a future prediction when it is plotted in the Growth Chart or in the tracking graph(see next section) showing the real Reliability Growth. Factors that is increasing the starting point are:

- General complexity and reliability levels of the product
- Amount of unproven, untested new design content
- Effectiveness of the design effort in proactively designing reliability into the product and avoiding failures

4.3.3 RG Tracking

By tracking the Reliability Growth during the development testing, plotting the actual Reliability Growth in a Tracking Chart, the Reliability Growth can be monitored. By comparing the actual growth according to the predicted growth from the Growth Chart, the particular development-testing phase can be evaluated. If the Reliability Growth was lower than expected more resources can be assessed in future developmental testing or vice versa. The information available from RG tracking can also provide as input for future predictions. From this a more accurate starting point that better corresponds to the products' current embedded reliability and a more trustworthy Growth Rate according to the current problem solving effectiveness in the project can be used for predicting the RG for future development testing phases. This will increase the trustworthiness and bring more reliable results from future RG predictions. In that sense the RGM needs a burn in period, increasing its accuracy over time, and the more developmental testing that is performed the more reliable will the outcome of the prediction's be.

5 SITUATION ASSESSMENT

The situation assessment aims to describe GTT's way of managing reliability, working with reliability improvements and reliability predictions. Initially an overall description is made for Quality & Customer Satisfaction (Q&CS), the organization within GTT that is responsible for assuring quality of the products. It follows by a description of how the responsibility for reliability is transferred within the organization during the product's life cycle and how the organization is working with improving the reliability of the product. Further, the reliability prediction process within the organization is presented and finally the case project, the new FH-series project, is presented.

5.1 QUALITY & CUSTOMER SATISFACTION

The Quality & Customer Satisfaction (Q&CS) organization can be seen as consisting of two sub-divisions, a project organization and a maintenance organization, who respectively participate in the project process and the maintenance process. Briefly, the project organization is global and manages the quality assurance processes during the development of a new product. The maintenance organization, which itself is divided in geographical regions, which additionally are divided in module teams according to the truck's functional segments, instead assures products quality on the aftermarket. When a development project is completed and the ingoing content is ready for being implemented to future products on the market, the project organization hands over the responsibility for the contents' quality assurance to the maintenance organization for the specific region as seen in Figure 13.

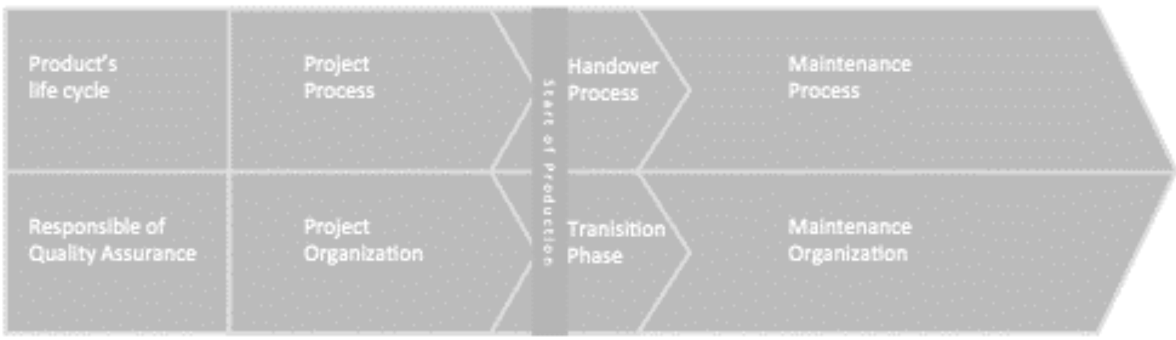


Figure 13, Responsibility of quality assurance throughout a product's life cycle

Figure 13 describes how a typical project flows from the project organization to the maintenance organization, visualizing how the project process shifts into the maintenance process with an intermediary handover process; this is a simplification of the reality. Seen from a larger perspective the two organizations are working in parallel and in some means concurrent, as seen in Figure 14.

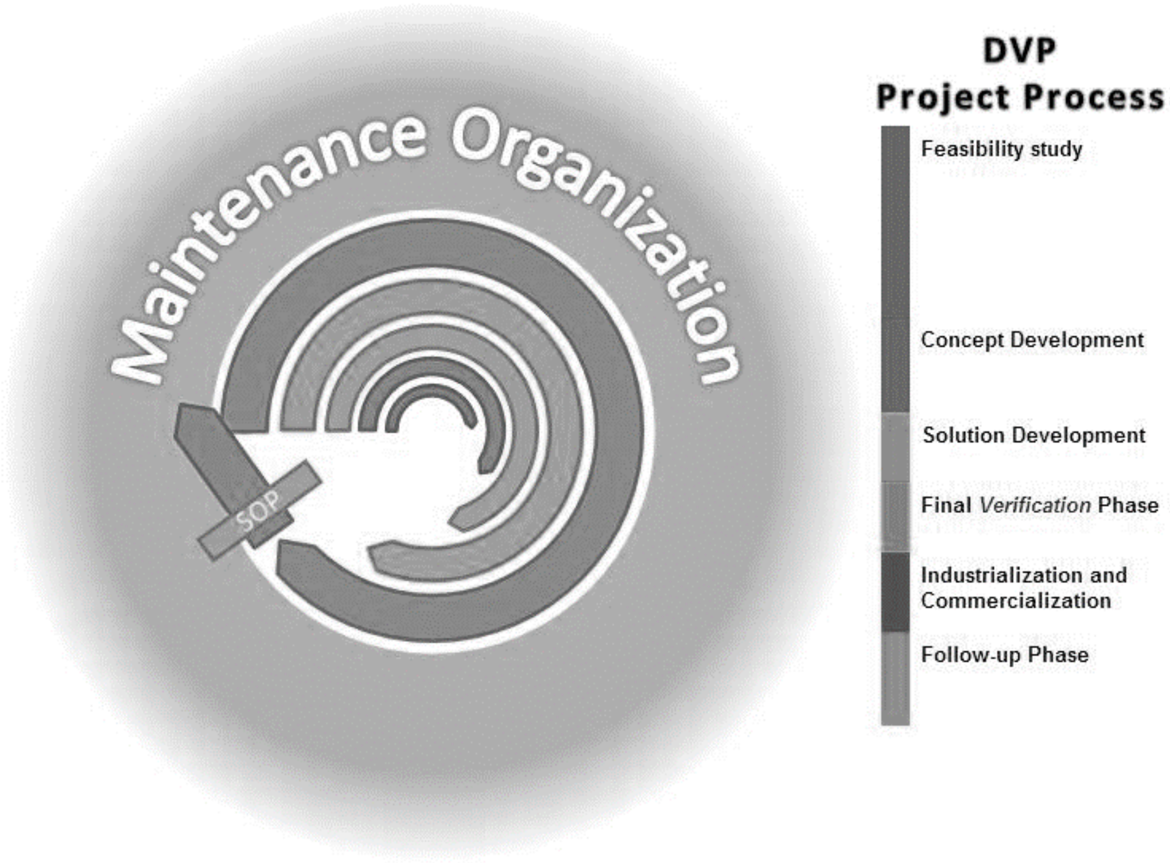


Figure 14, The interface between project and maintenance process

In the inner project process several development projects are run at the same time. As the development projects are finalized and the targeted reliability for the project's content is considered as reached the new content from the development projects is transferred out to the outer maintenance process as new truck models, features or upgrades of existing parts. In the outer maintenance process the content's reliability later is monitored. If unexpected issues arise from variation existing between the design reliability and the field reliability according to Figure 7, additional reliability growth is achieved through further development within the maintenance process.

After identifying a critical issue and a contrary improvement action is initiated, the maintenance organization is collaborating continuously with the project organization throughout the solving process. Within the solving process a personal from the maintenance organization, a Project Quality Leader (PQL), facilitates the project, responsible for bringing the affected people from different functions within the project process together to solve the issue. If the issue is global a Global Project Quality Leader (GPQL) facilitates the project. Thus, the people from the project process who initially was responsible for developing the affected parts are also solving later issues that arise. The workflow within the maintenance process can therefore be seen as a continuous interacting process between the maintenance organization and people from the project process.

The new content stays within the maintenance process until it is faded out from the company's product portfolio and disappears from the maintenance process' scope. Likewise, initially in a new development project the project organization in some sense gathers field experience from the maintenance organization when planning for the project, however the collaboration throughout the rest of the project process is not that frequent as in the maintenance process. Here the interaction generally starts again when the project has reached the follow-up phase and the quality assurance responsibility is handed over to the maintenance organization through the earlier mentioned handover process, see Figure 13.

5.1.1 Quality Improvement Actions

Obviously, it is desired that a product achieves an adequate level of reliability in the end of the project's development process, but due to the complex nature today's products that is rarely the case. Quality improvement actions, also referred to as QAs, are therefore implemented continuously within both the project process, after issues has been reported in the developmental testing and within the maintenance process as indications of their need are received from the field as warranty claims. Depending on in which of the processes at GTT it takes place and the characteristics of the issues, different improvement actions are initiated. Figure 15 visualize the different types of improvement actions together with where the indication of their need comes from, which organization of the Q&CS that is responsible for the actions and how the solution is implemented to the products on the market.

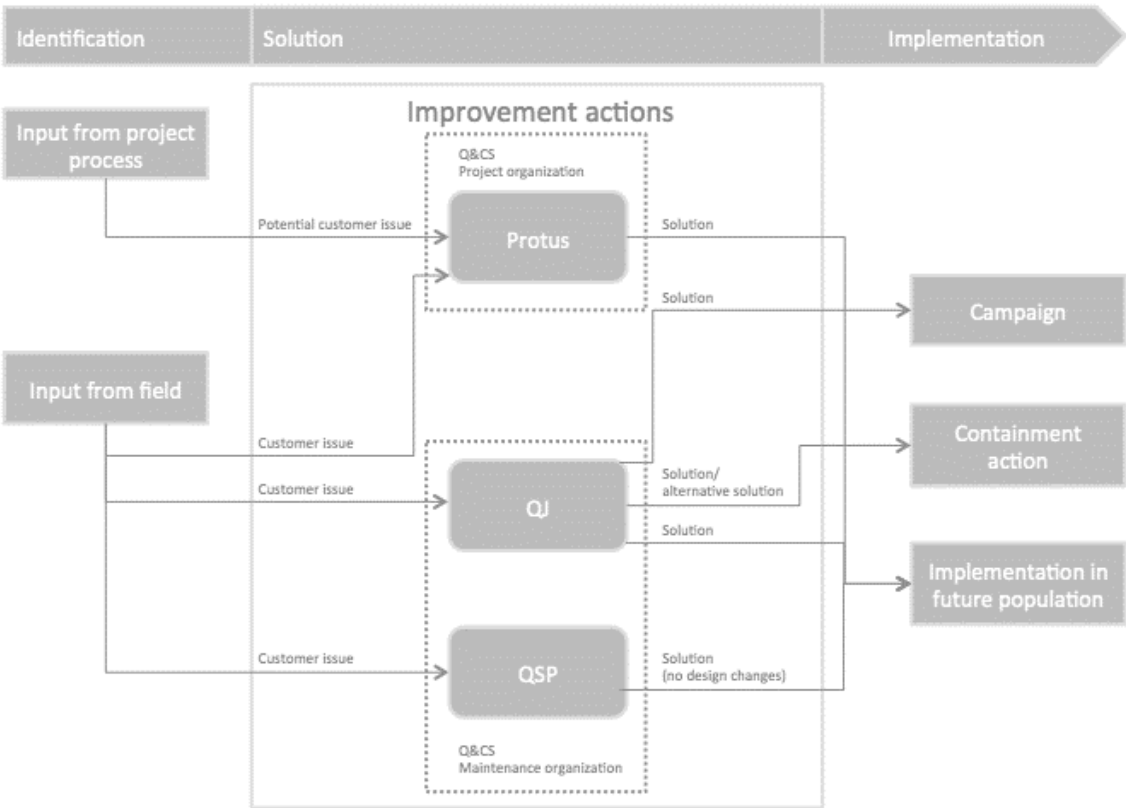


Figure 15, Improvement Actions within GTT

PROTUS

PROTUS is the standard procedure for solving quality issues in the project process. Normally, a PROTUS is started based on a failure that is reported during developmental testing. In some cases projects are released on the market before the responsibility of the quality assurance for all included content is handed over to the maintenance organization, then a PROTUS can be started based on claims from customers and the responsibility for solving the issue still stays at the project organization. The solution from a PROTUS is implemented to the current design of the truck and thus implemented in all future produced trucks.

Quality Journal (QJ)

Quality Journal (QJ) is the maintenance organization's standard procedure for solving quality issues and is started based on information gathered from the field, reported through warranty claims from customers. When deciding upon to start a QJ, the maintenance organization is considering number of claims associated to the issue, warranty cost for the issue and if the issue leads to unplanned stops for the customer. The solution is implemented to the current status of the truck and thus implemented in all future produced trucks. For some more critical issues containment actions can be needed, which is temporary solutions used until the root-cause to the problem is found and solved. And in even more severe cases campaigns can be necessary, which means that all trucks on the field are brought into service for implementation of the new solution. It is also possible to highlight a QJ with a red card, this means that the QJ is of highest importance and needs to be prioritized by all involved persons in their daily work in order to be solved as fast as possible.

Quick Solving Process (QSP)
For solving issues related to the manufacturing process or suppliers the Quick Solving Process (QSP) is the preferred action. These are often issues where the solution does not lead to any design changes on the truck itself. The time to find the solution is therefore in comparison to a QJ often short and implemented directly in future assembled trucks, e.g. as a change in the manufacturing process.

5.2 PROJECT ORGANIZATION

The process for executing a new development project is based on the Development Process Project Handbook, which is an internal guide describing how projects should be organized and executed within GTT. It proposes which activities to perform and gates to use for monitoring the progress depending on the scale of the project.

The Project Manager Quality (PMQ) is responsible, together with a reliability engineer, to prepare a reliability growth plan and assure that the project get through the intended plan. This plan contains the amount of reliability testing that is considered necessary to reach the intended reliability target and is updated continuously. For major projects, the complete vehicle testing starts in the end of the Solution Development phase, when the project has reached C-status. From this moment the test data used for the RGM prediction of FF12 at SOP and SOP+12 months is collected, for more details see next section ITI's RG model 5.2.1. The development testing continuous until the development process is completed and the product has reached a satisfying level of reliability, being ready for production. The project process ends with a "follow-up phase" where lessons learned from the project are recapped, but more important the responsibility of the quality assurance for the new content are handed over to the maintenance organization, this process is described in more detail in the handover process section 5.3.

5.2.1 ITI's RG model

In a new major development project the project organization use RGM software provided by ITI. The RG model used in the software is based on Duane's model for reliability growth see section 4. Theoretical Framework. In a previous master thesis performed at GTT Le Douarin (2009) provides a "theoretical user guide" of ITI's tool, which explains the theory and mathematics behind it in more detail. The software is used throughout the whole developmental testing process to make sure that the product's reliability is increased as planned and will be able to reach the target set initially in the project. The software has two functions, RG Planning and RG tracking. It enables to predict the reliability that the project's content will have at a certain time of the development process (RG planning) and track the outcome of the reliability growth within each reliability growth test phase (RG tracking).

During tracking, the total count of identified failures (subtracted with solved failures during the test phase) is graphically visualized during one test phase, in order to show the instantaneously FF12, which is GTT's way of measuring reliability. The tracking of the reliability growth will indicate if the planned FF12 targets for the project can be met or if more resources will be needed to reach the target before SOP. The targets that are used are the expected FF12 value at SOP and 12 months after SOP, in this report referred to as FF12 at SOP and SOP+12. After each development test phase the input parameters in the overall RG plan can be adjusted with respect to the received information from the previous test phase, which increases the accuracy in future predictions and planning. In that sense the software learns from the previously conducted reliability growth testing and the output gets more reliable the more the software is used. The information received from each reliability growth test phase consists of the total amount of identified failures, solved failures and the total running distance of the trucks taking part in the test.

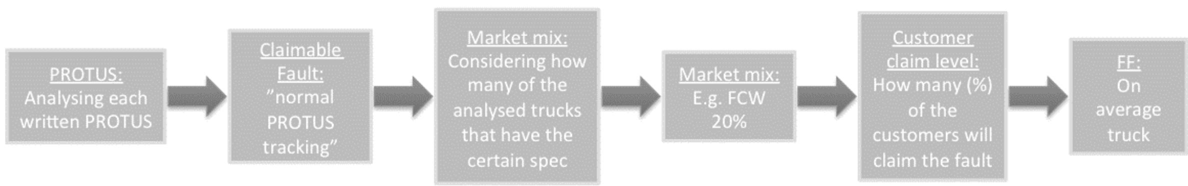


Figure 16, PROTUS revision process

Every other week the reported failures from the tests are reviewed together by a PMQ and a reliability engineer according to the procedure in Figure 16. Then they decide if the failures should be included in the FF12 prediction for SOP and SOP+12 or not. A failure is only included in the input data for future FF12 predictions if it is a failure affecting the Design

Reliability and is expected to appear as a failure in the field. If a failure is judged as a potential failure in the field, its hit rate on the overall FF12 is evaluated. This hit rate is used when estimating how effective the solution to the problem will be on the overall FF12 value for the truck. This is necessary since the trucks on the field will not have the same specifications and an improvement on a specific part therefore not will affect the FF12 value for all trucks on the field. The hit rate depends on how many of the trucks on the field that is estimated to have the affected technical specification and how inclined the customers is expected to be for claiming the failure. All of this work is a qualitative judgment based on experience and individual expectancies of the PMQ and the reliability engineer.

5.2.2 Peak factor

By observing historical FF12 data for projects at GTT a reoccurring FF12 peak can be identified in conjunction with a market release for their projects. This reveals that the products often experiences infant mortality problems or child diseases. As only the failures related to the Design Reliability are included in the FF12 predictions based on the ITI's RG model the predictions are only valid, as perceived field reliability by customers, for a stable product. Meaning that the field reliability equals the design reliability because of robustness against all intermediary variation. To compensate this the FF12 predictions at SOP, lying within the peak period and where a stable product not has been achieved, are multiplied with a peak factor. This peak factor is based on FF12 data from the experienced peak in a historical project. The peak factor is calculated by dividing the highest attained FF12 value within the peak period with the FF12 value for the stable product after the peak period, see Figure 17 for a graphical example.

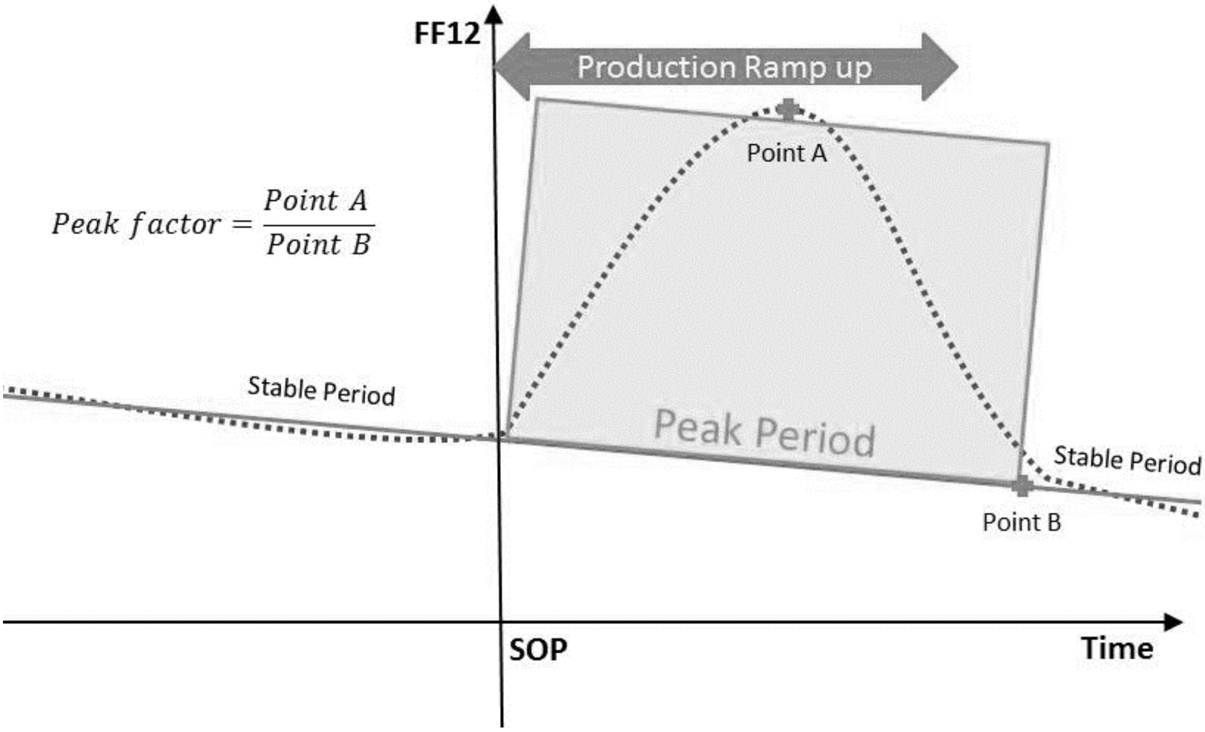


Figure 17, Illustration of peak factor

5.2.3 Engineering Reports

To track and document the project's reliability growth an Engineering Report (ER) is released by a reliability engineer, which is updated regularly throughout the project. It aims to analyze the current concepts and plans regarding reliability and tell if the product requirements can be met for the complete vehicle. The report is based on analysis made with ITI's RG model where the reliability growth of each module team is evaluated.

5.3 HANDOVER PROCESS

When the product is ready for market introduction the project organization hands over the responsibility of the product's quality assurance to the maintenance organization. The responsibility is delivered through a process, which aims to secure that the project has finished the development of all new content in the project.

The handover process starts within the project organization. All parts included in the project are internally revised and a handover list, based on part number, is created. Next step in the handover process is a cross-functional meeting, still within the project organization, to verify that the product is ready for handover according to all disciplines. The next step includes the PQL who is invited to review the handover list. If the PQL does not accept the list and considers that there still is work to be done within the project organization the PQL give recommendations regarding further work to be done for acceptance. When the PQL accepts the products the maintenance and the project organization review the handover list together and agree on that the content is ready for having the responsibility transferred. The last step includes the official agreement.

The criteria's evaluated during the handover can be disregarded for special circumstances but having the responsibility handed over anyway. This requires all parties' approval on that the products' maturity level is acceptable; there are for example some variants that are built very seldom and understandably therefore cannot live up to all requirements.

5.4 MAINTENANCE ORGANIZATION

The maintenance organization works within the continuously ongoing maintenance process, which aims to guarantee a high perceived customer quality by reacting on customer complains to improve the products´ quality if needed. The customer claims are gathered from the service centers performing the repair of the trucks. From this information the quality actions are initiated as described in Quality Improvement Actions section 5.1.1. However, none of these indicators works if the customers not yet have reported a claim and often several claims is needed to draw the attention, which causes a lag in responsiveness at the maintenance organization.

5.4.1 Extrapolated FF12 Forecast

The maintenance organization divides trucks released on the market into populations based on their assembly month. For these populations the maintenance organization continuously monitors the FF12 values received from warranty claim data, in order to assure that the customers receives the intended quality. A population's FF12 value is accepted when more than 65% of the population has reached 12 months in service (MIS). This causes a delay meaning that the FF12 value for a population not will be available, sometimes up to 14 months after the assembly month. FF12 at SOP+12, therefore means that it is the FF12 value for the assembly month manufactured 12 months after SOP.

To be able to monitor the populations' current FF12 value continuously and take actions on undesired trends there is a need for the maintenance organization to predict the FF12 values before the real values are received. To do this, it uses the current information available for the population at the specific time together with information from populations with earlier assembly months, which has a higher MIS average and therefore more available FF data. By this method the FF12 values for an assembly month can be extrapolated based on the population's latest available FF values for less months in service, e.g. FF3, FF6 or FF9 and an average of the historical gap between the corresponding FF values and the FF12 value for earlier populations.

E.g. to predict the FF12 for Dec-11, from the average of the historical gap between FF9 and FF12 for a selected time interval containing populations with earlier assembly months a factor is calculated, this factor is later multiplied with the real FF9 value for Dec-11 to obtain FF12.

5.5 The New FH-Series Project

The new FH-series project is unique in concern of the project's extent and the large degree of new technology. The project consisted of an upgrade of the classic FH series, which is one of Volvo Group's most sold trucks, and resulted in the first new model of the series for 19 years. The new model is considered as a premium truck and has been received well from the critics. It was awarded the international truck of the year 2014 by leading commercial vehicle journalists, representing 25 magazines throughout Europe (Volvo Group, 2013). Volvo Group's intention is that the model should be the new leader in long haul by providing unparalleled driver comfort and operating economy (Volvo Trucks, 2014).

The project did not only contain a visual remake but also included a new electrical architecture and advanced software who enabled many new technical features, e.g. Telematics Gateway, a feature that allow constant communication between the truck and the service center. By receiving truck data wireless the service centers can provide higher service, e.g. by planning the need for next service stop or upgrade changes in the truck's software on distance.

The project's scope and scale made it to one of the most demanding projects at GTT up till now and all new content mean that there was a high need of executing a large degree of developmental testing, in order to verify the new technical solutions and assure the quality of the truck (Volvo Trucks, 2013). The amount of developmental testing is the highest in any project at GTT ever performed and this has provided good circumstances for reliability growth predictions, since it means a large amount of input data and time for the ITI's RG model to modify itself. The high level of testing does not only count for the high number of mileage but also the high degree of customer focused vehicle testing, where the customers' requirements has been in focus and the test drivers consisting of professional drivers had the opportunity to influence the design of the tests, who also was conducted under highly strict procedures (Volvo Trucks, 2013). In the latter part of the development testing process some field test at customers also was conducted.

The large scale of the project and the high degree of new content led to that the project in the end was running out of time and developers found it hard to reach the deadlines. This was particularly the case for content related to module team *C* and *D* which was described in the ER’s. In the beginning the quality issues were so severe that the top management declined to deliver the trucks produced during an initial period X. They were instead kept until a majority of the quality issues were solved and the FF12 predictions indicated a lower outcome.

6 ANALYSIS OF GTT'S ABILITY TO PREDICT FIELD RELIABILITY FOR MAJOR PROJECTS

This part aims to qualitatively analyze GTT's ability to predict FF12, with the use of ITI's RG model, before the market introduction. To be able to perform this qualitative analysis, this part starts with a quantitative analysis of the FF12 peak for the new FH-series' project. Then follows an evaluation of the outcome of the FF12 predictions within the New FH-series Project. Finally, the findings from the quantitative analysis, the situation assessment and the outcome of the predictions within the New FH-series project are used to perform the final qualitative analysis against the theoretical framework.

6.1 QUANTITATIVE ANALYSIS

The quantitative analysis will provide as a basis to the qualitative analyze of ITI's RG model's ability to predict the reliability in conjunction with a market introduction. The quantitative analysis consist of two parts, firstly the New FH-Project's FF12 peak is analyzed and secondly the outcome of the last predicted FF12 values within the project are evaluated.

The analysis is based on three sources of data. Firstly, all warranty claims for trucks assembled between October-2012 and May-2014 where the last reported failure was in 11th of June-2014, secondly data from the Quality Actions (QAs) executed to improve the new FH-series' reliability after SOP and thirdly forecasted FF12 data from the maintenance organization's monthly reports.

6.1.1 Description of the FF12 peak for the New FH-series Project through data mining of warranty claim data

This part of the quantitative analysis aims to describe what type of claims that caused the FF12 peak that occurred in conjunction with the market introduction for the new FH-series. Instead of predicting the peak, Volvo Group would evidently benefit even more from preventing the peak to happen at all. Therefore this analysis in addition aims to describe the peak in a way that the maintenance organization can use it for further evaluation of the root-cause to the FF12 peak and to understand how they can work to reduce its magnitude.

6.1.1.1 The FF12 peak described in means of module teams

As mentioned earlier GTT is in a high degree organized according to the truck's different functions, referred to as module teams. Accordingly, the predictions from ITI's RG model are also divided into these module teams when presented in the Engineering Reports. As mentioned in the section 5.5 *The New FH-Series Project* the Engineering Reports indicated that two of the module teams were expected to represent a large share of the warranty claims. In order to verify if this prediction reflected the outcome of the warranty claims, the analysis divides the warranty claims among these module teams. Further, the maintenance organization's prioritization among these module teams for its improvement work is analyzed, to see if it represents the severity of the module teams according to the warranty claim's distribution. Due to confidentiality, the module teams are numbered instead of mentioned by name.

6.1.1.1.1 The amount of warranty claims among the different module teams

According to interviews with personnel from the project organization and Engineering Reports it was known early in the project process, through development testing, that the development of Module teams *C* and *D* lacked behind in schedule and that these areas already were expected to be considerably responsible for the failures within the peak. The warranty claims reported during the studied period have been divided into the different module teams to see the real outcome and how each module team impacted the peak. The result can be seen in Figure 18.

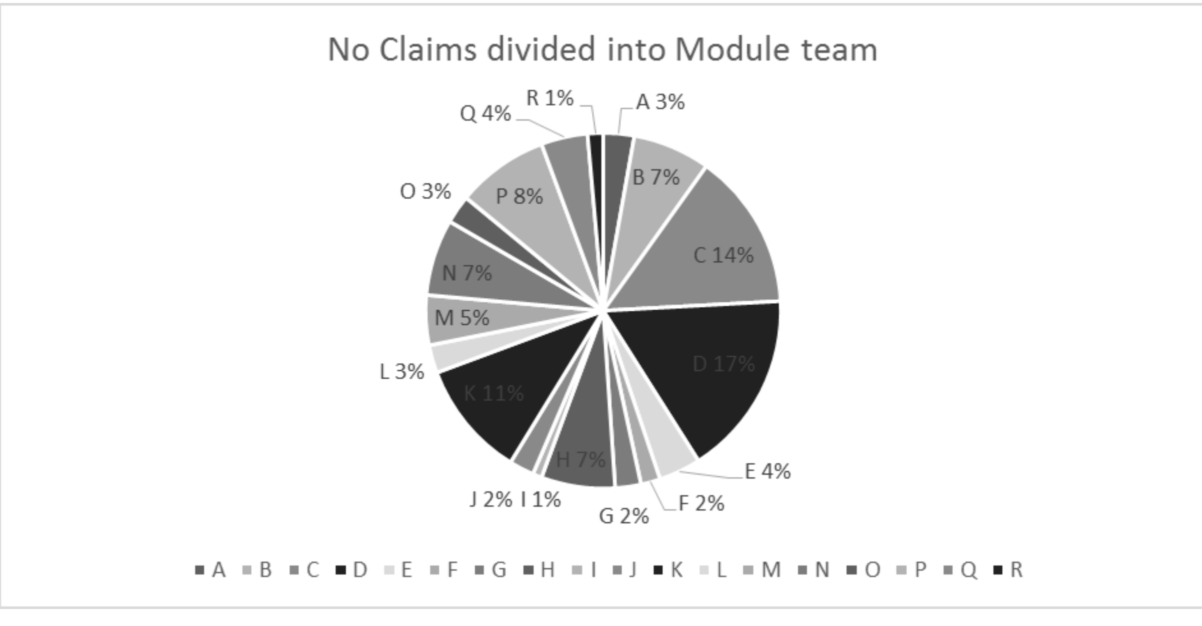


Figure 18, No. claims divided into module teams

The picture clearly shows that the claims related to failures within module team *C* and *D* are major contributors to the peak as they together are responsible for around 30% of the total amount of claims.

The amount of warranty claims is the most important indicator for the maintenance organization when identifying the need for a QA, but there are other indicators that GTT uses when prioritizing failures on the trucks. Failures causing breakdowns is one of these factors, a failure leading to a break down is extra critical to the customer meaning that the truck stops and cannot be used again until the broken part are replaced. Hence, it could be of interest to see how these failures are distributed. Figure 19 shows the criticality of the failures within the different module teams in means of breakdowns.

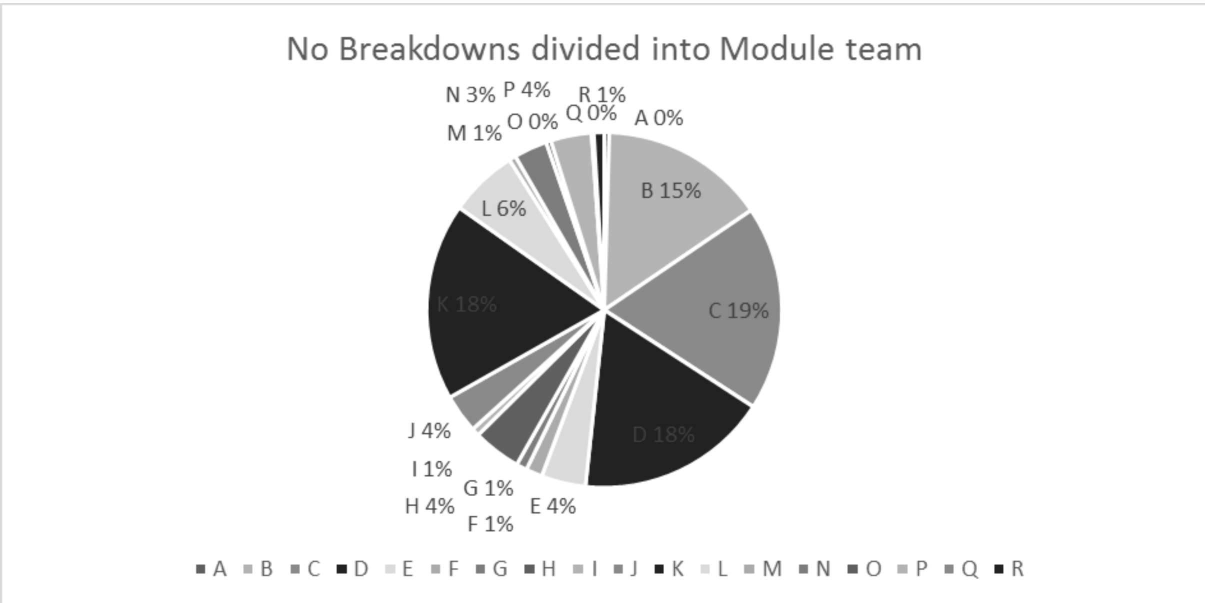


Figure 19, No. breakdowns divided in module teams

The left pie chart in Figure 19 shows that there are primarily four module teams that are responsible for almost 70% of the total amount of breakdowns, module team *B, C, D* and *K*.

6.1.1.1.2 The maintenance organization's response to failures among the different module teams

The distribution of the failures are linked to how the maintenance organization are prioritizing the warranty claims. An extreme example could be if maintenance would put all their assets to decrease the impact of failures in a specific module team. They would in that case have a high growth rate (G) in this specific module team and the impact of these failures would not appear as crucial as it does today. Thus this subchapter will give a brief overview of how they have prioritized the problems during the two years that the truck have been on the market.

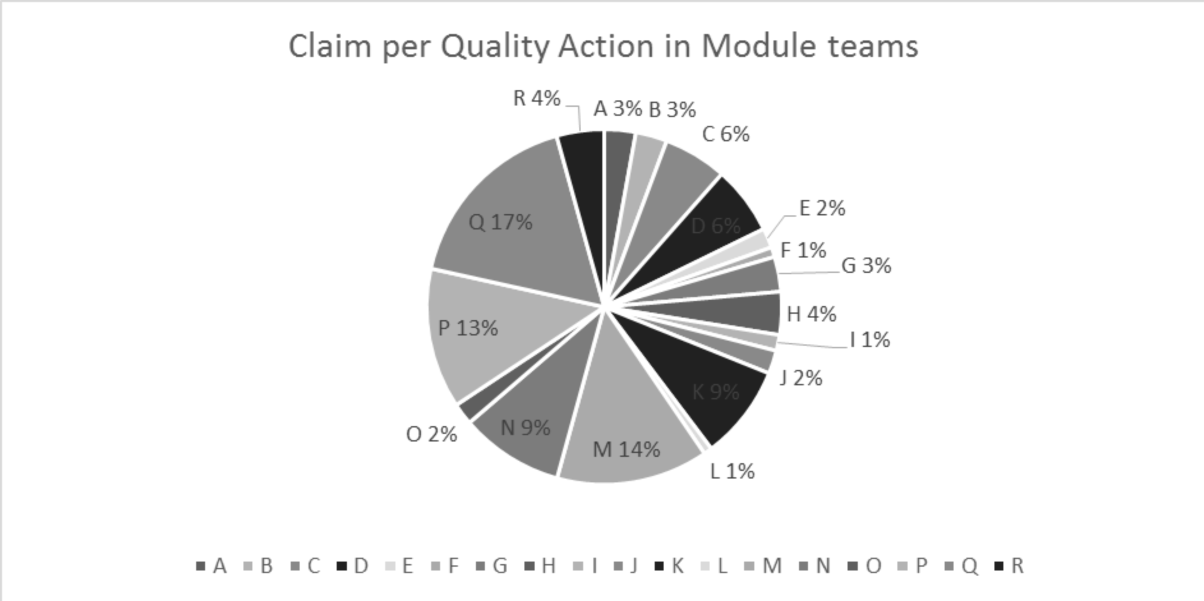


Figure 20, Claim per Quality Action in Module teams

The pie chart to the right in Figure 20 shows how many claims per QA each module team. Here it shall be remembered that when prioritizing issues to solve, the PQL in respective module team base the decision on more than the amount of claims and breakdowns that have occurred, even if these two parameters are of high importance, and thus it is of importance to understand that this analysis only is used to see if there are any module teams that distinguish itself. The pie chart shows that none of the module teams that are mentioned as extra important, from the perspective of amount of breakdowns and amount of warranty claims, stands out with a high amount of claims per QA. This indicates that these module teams are prioritized and that the maintenance organization is working to improve the reliability within these module teams.

One more aspect that can be considered in this section of the analysis is that one QA can be dedicated to solve a high amount of warranty claims. Figure 21 illustrates a Top45 Pareto together with a pie chart, which shows the distribution of the warranty claims included in the Pareto which covers about 30% of the total amount of the warranty claims that concerns the new FH-series.

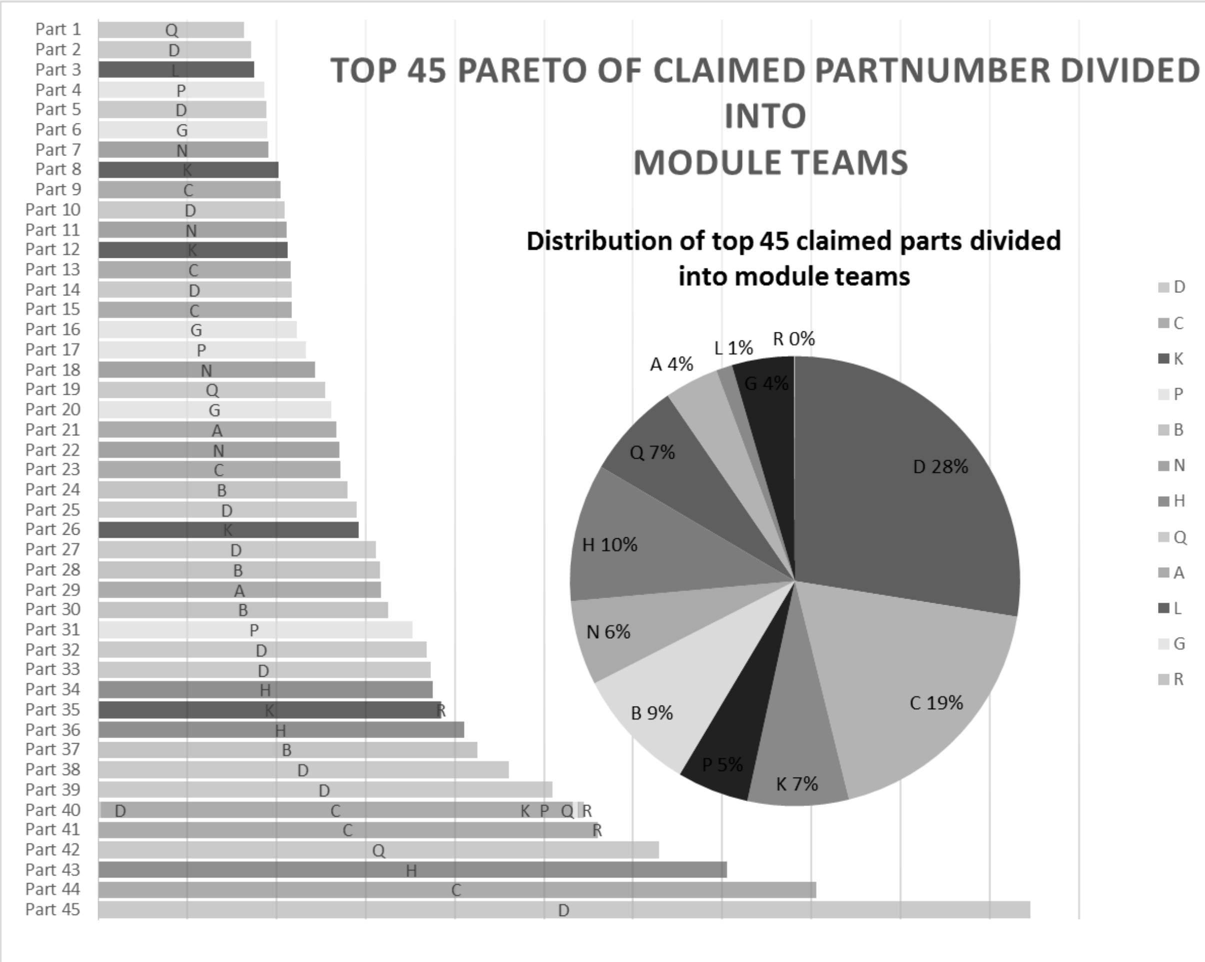


Figure 21, Top 45 Pareto of claimed part numbers divided into module teams

It is common that QAs are allocated onto part numbers, especially for part numbers that are claimed frequently. If a module team has a lot of the claims in the top45 Pareto it will have a high rate of claims per QA which can be connected to the analysis of Figure 20. For example does module team *C* and *D* have high rates (nearly 50%) of the most common reported part numbers, which further supports that these module teams are highly prioritized in the maintenance organization. This again proves that module team *C* and *D* are the module teams that were not yet finished in the project process and therefore contributed highly to the FH12 peak. It also proves that the maintenance organization was aware of the problems and dedicated a high amount of resources to solve the module teams quality issues.

6.1.1.2 Categorization of the failures causing the peak into failure types

The grouping of the warranty claims aims to identify what failure types that are the main driver behind the peak. The grouping of the warranty claims into failure types is also of interest since ITI's RG model, according to the theory and interviews, only considers developmental failures. Therefore the distribution of the failure types within the FH-series' peak can be used to verify the accuracy of ITI's RG models predictions, both in peak and stable periods. The failure types have been decided upon through the interviews, where the interviewees have shared there perception of what causes the peak and how to group these failures, together with the literature from Prabhakar Murthy et. al. (2008). This resulted in a categorization of the warranty claims into four major failure types which aims to separate claims depending on where the failures occurs, namely; *Development*, *manufacturing*, *supplier*, *customer perception* and *other*.

Development	Failures that occur due to mistakes made in the design.
Manufacturing	Failures that occur due to mistakes made in the assembly line.
Supplier	Failures that occur due to mistakes made at the supplier.
Customer perception	Failures that are reported even if the product is according to specification.
Other	Failures that are hard to categorize in only one of the other failure types or that does not fit in any of the failure types.

Figure 22, Description of the failure types

The claims reported from the service centers were not pre-grouped into these categories and thus there was a need to categorize them manually. The authors grouped the QAs into what kind of failure type the QA was solving and then connected the QAs to their respective part number, which is reported with each warranty claim. This was done with the help of an employee at Q&CS maintenance department who has a good knowledge of all active and closed QAs.

It was not possible to connect all part numbers to a QA why the uncategorized part numbers were categorized into six new groups, *Very often, Often, in between, Rarely, Very rarely and unknown part number*, depending on the amount of warranty claims reported on the part number. These groups were created just to see how the distribution of the more severe uncategorized part numbers are in the module teams and because the distribution did not show anything extraordinary are these groups not analyzed any further in the report. Almost 50% of the reported claims could be grouped into the failure types and the distribution can be seen below in Figure 23.

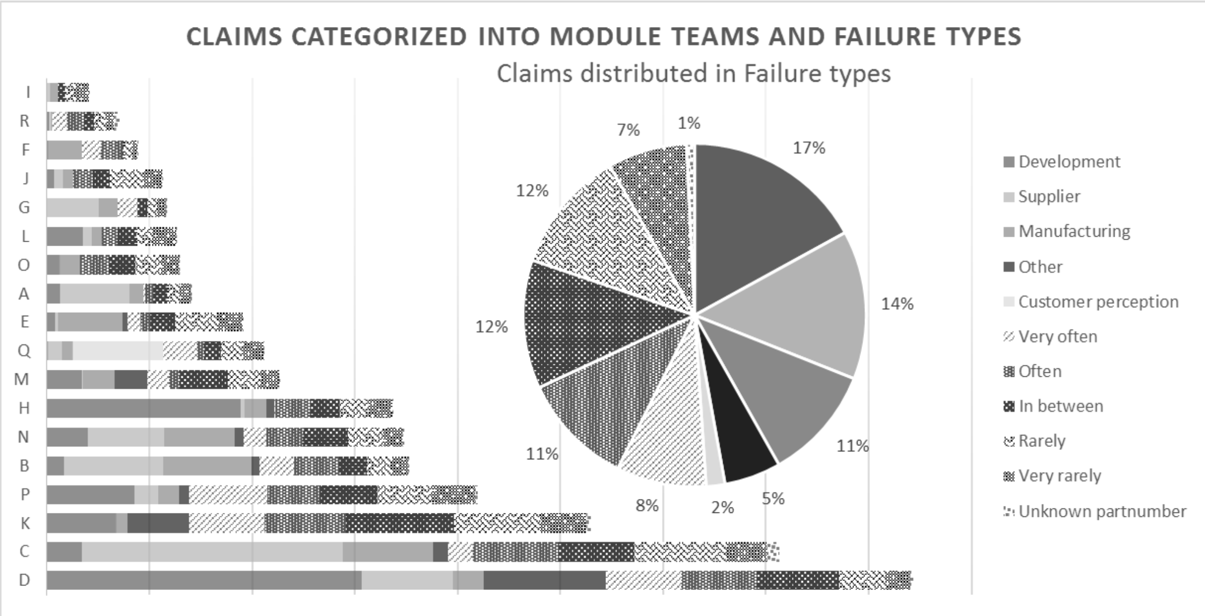


Figure 23, Claims categorized into module teams and failure types

One has to remember that the categorization of the claims was done manually and that there were several QA that was hard to connect to a single part number. Thus cannot Figure 23 be used to review how many claims that are covered by Quality Actions but only give indications of what types of failures that are represented in respective module team and what types of failures that drives the peak in this specific market introduction.

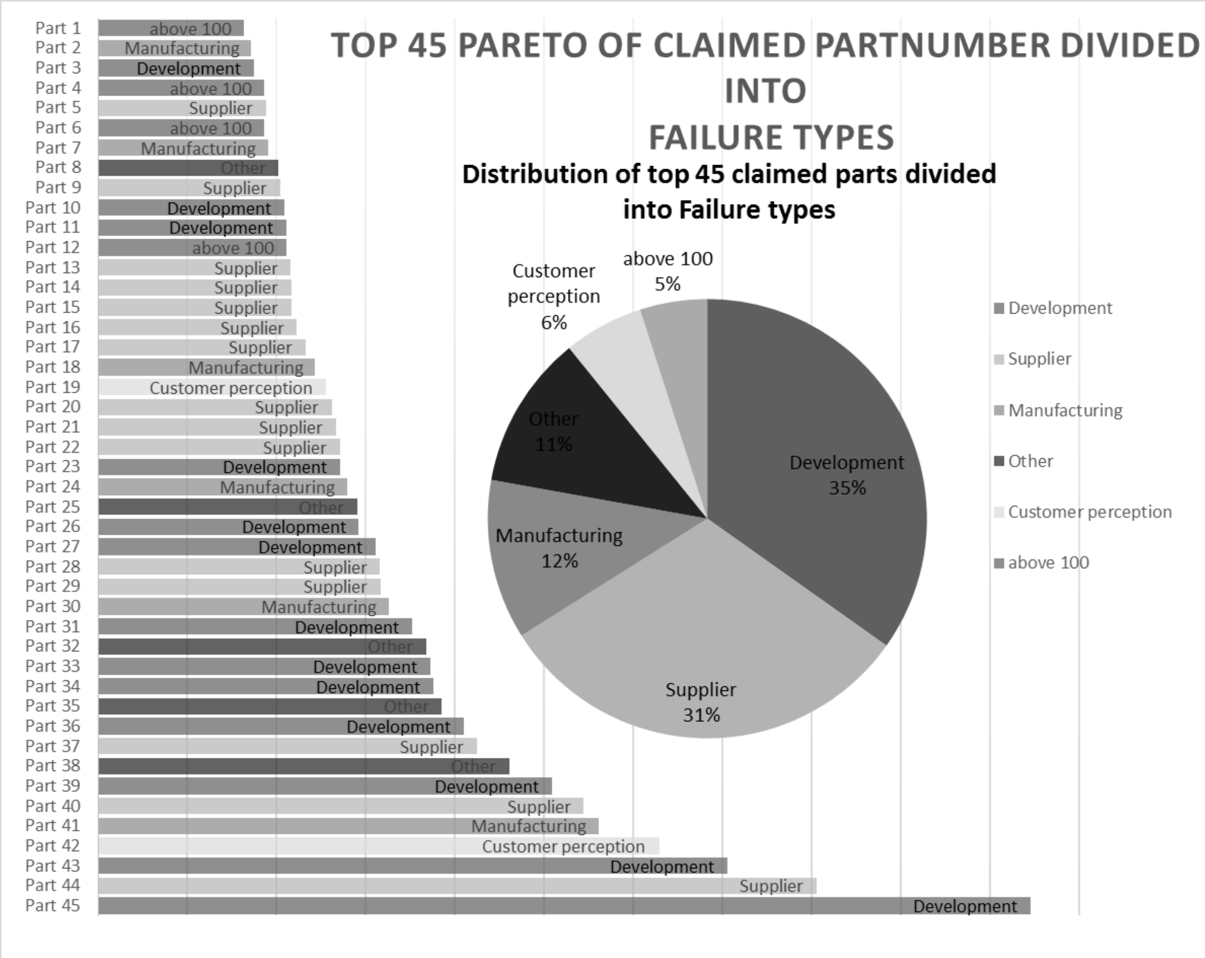
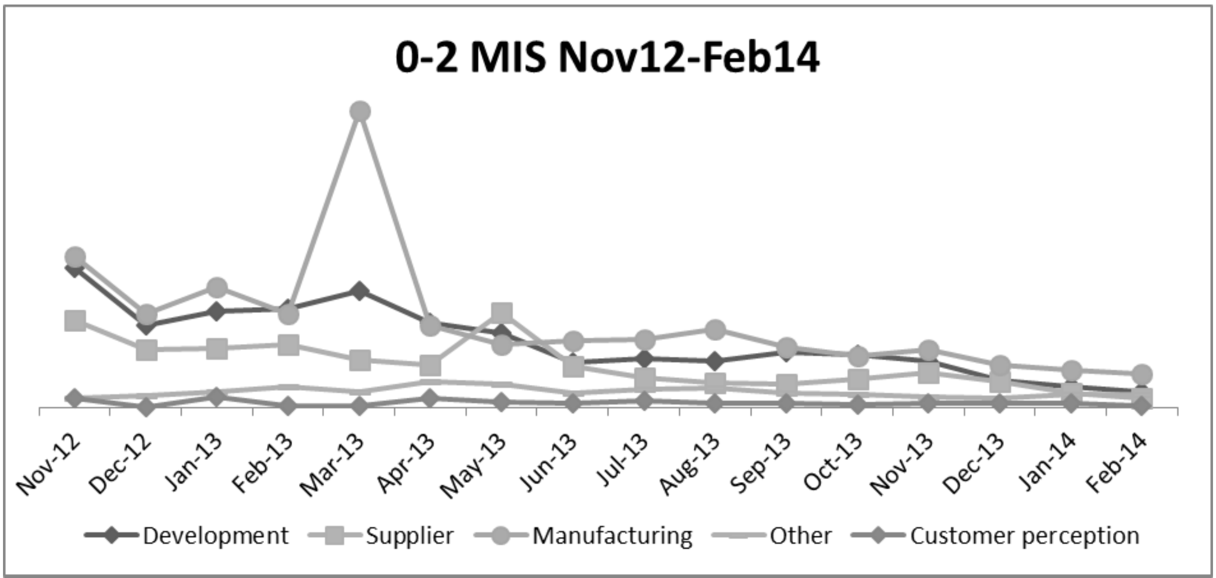


Figure 24,Top 45 pareto of claimed part numbers divided into failure types

Figure 24 shows the top claimed part numbers divided into failure types and can be used to analyze which failure types that have been critical to build up the peak. Development and supplier failures represent around 2/3 of the top 45 claimed parts during this project's peak.

Figure 25 and Figure 26 shows how the failure type's FF change during the peak with aspect of assembly month and month in service of the trucks. The graphs only contain data from warranty claims that were possible to categorize into the failure types. The graphs have different time span depending on the maturity level of the trucks represented in each graph, i.e. how many months in service (MIS) the trucks have, which is important to have in mind when comparing the graphs.


0-2 MIS Nov12-Feb14
Nov-12
Dec-12
Jan-13
Feb-13
Mar-13
Apr-13
May-13
Jun-13
Jul-13
Aug-13
Sep-13
Oct-13
Nov-13
Dec-13
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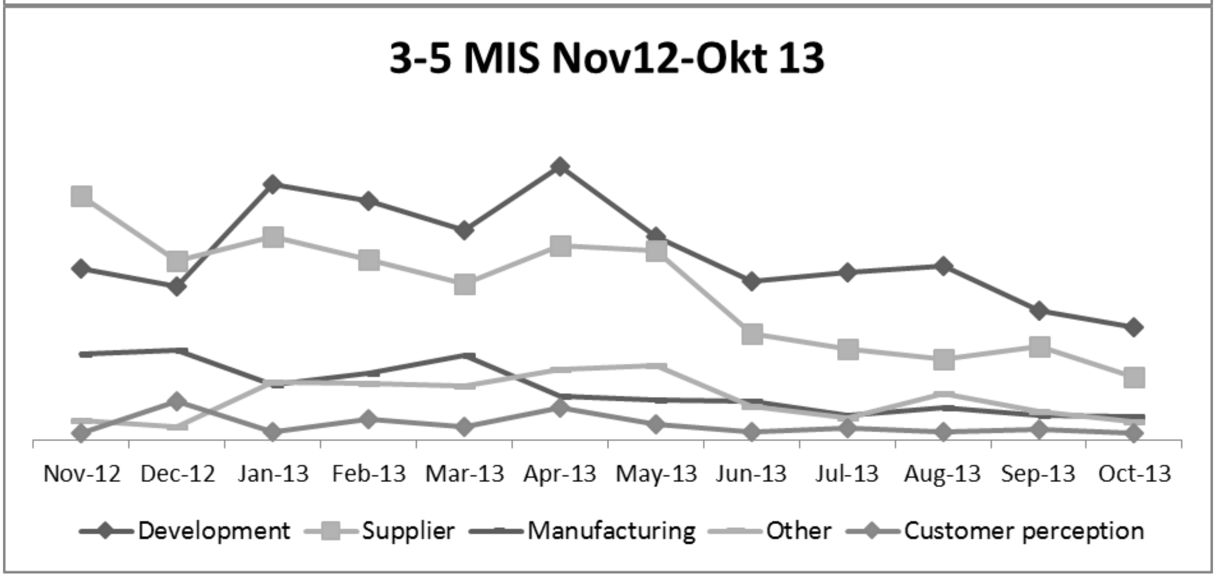
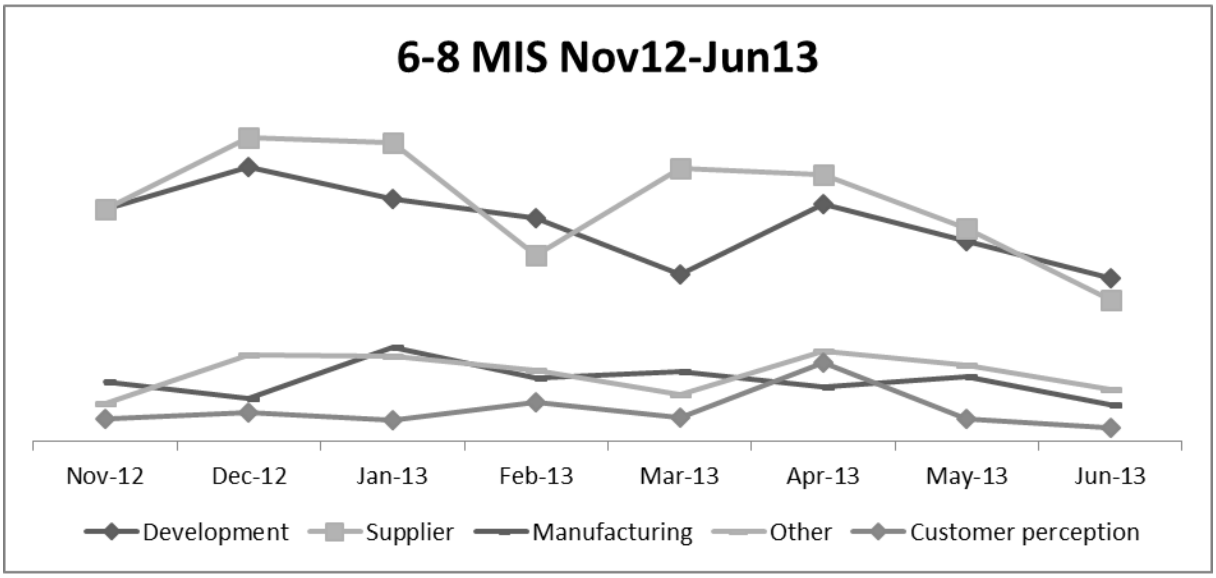
Feb-14
Development
Supplier
Manufacturing
Other
Customer perception


3-5 MIS Nov12-Okt 13
Nov-12
Dec-12
Jan-13
Feb-13
Mar-13
Apr-13
May-13
Jun-13
Jul-13
Aug-13
Sep-13
Oct-13
Development
Supplier
Manufacturing
Other
Customer perception


6-8 MIS Nov12-Jun13
Nov-12
Dec-12
Jan-13
Feb-13
Mar-13
Apr-13
May-13
Jun-13
Development
Supplier
Manufacturing
Other
Customer perception

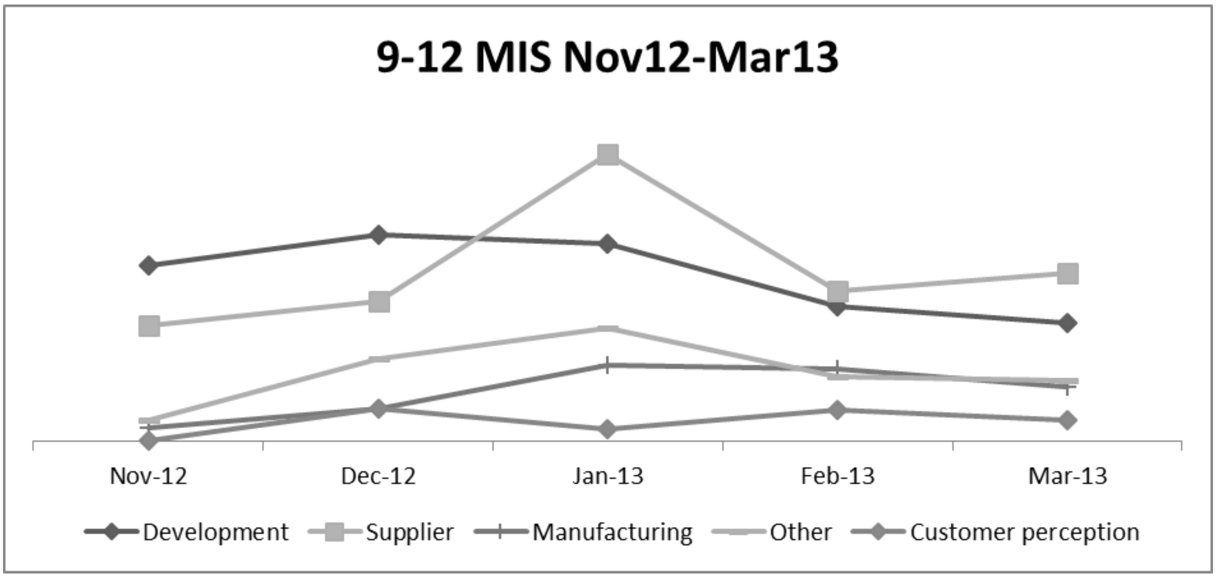


Figure 25, FF for the different failure types with different MIS periods

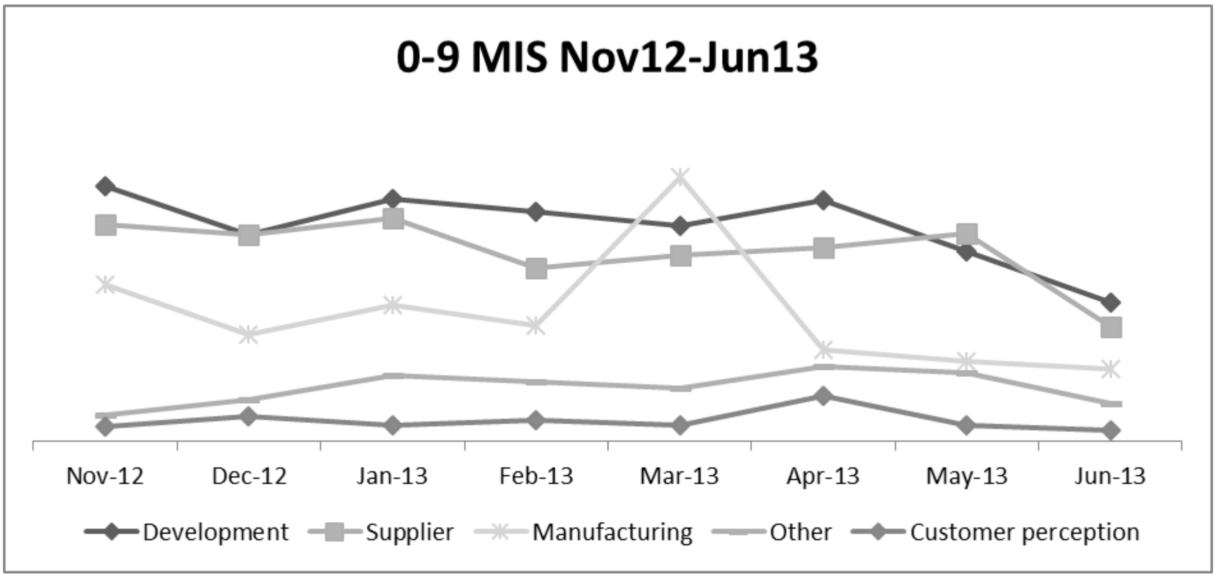


Figure 26, Total FF for the failure types

It is clear that the trucks have a higher rate of manufacturing failures for low MIS and it is also a trend that shows that the manufacturing failures are decreasing on the later populations which indicates that GTO has improved the assembly process of the trucks.

The manufacturing failure type decreases its impact after three MIS, probably due to fixes in the first service stop, but instead are the two failure types development and supplier that takes over as main drivers of the FF. But as seen in both the 3-5 and 6-8 MIS graphs these failure types also decreases their impact of the FF with the aspect of assembly month.

6.1.1.3 The failure types' effect on the duration of the new FH-series' peak

This part of the analysis will investigate what effect the different failure types have on the peak's duration. This will be done by analyzing the QA's lag from first identified failure to start of QA and the lead time of solving the QAs in respectively failure type.

Starting a QA is GTT's way of reacting on their customers complains, but as stated in the situation assessment there is a lag between when the customers encounter the first failure and when GTT is able to start resolving the issue. Figure 27 shows the average time it takes for the maintenance organization to react to a failure, and their average speed to execute a QA depending on the failure type.

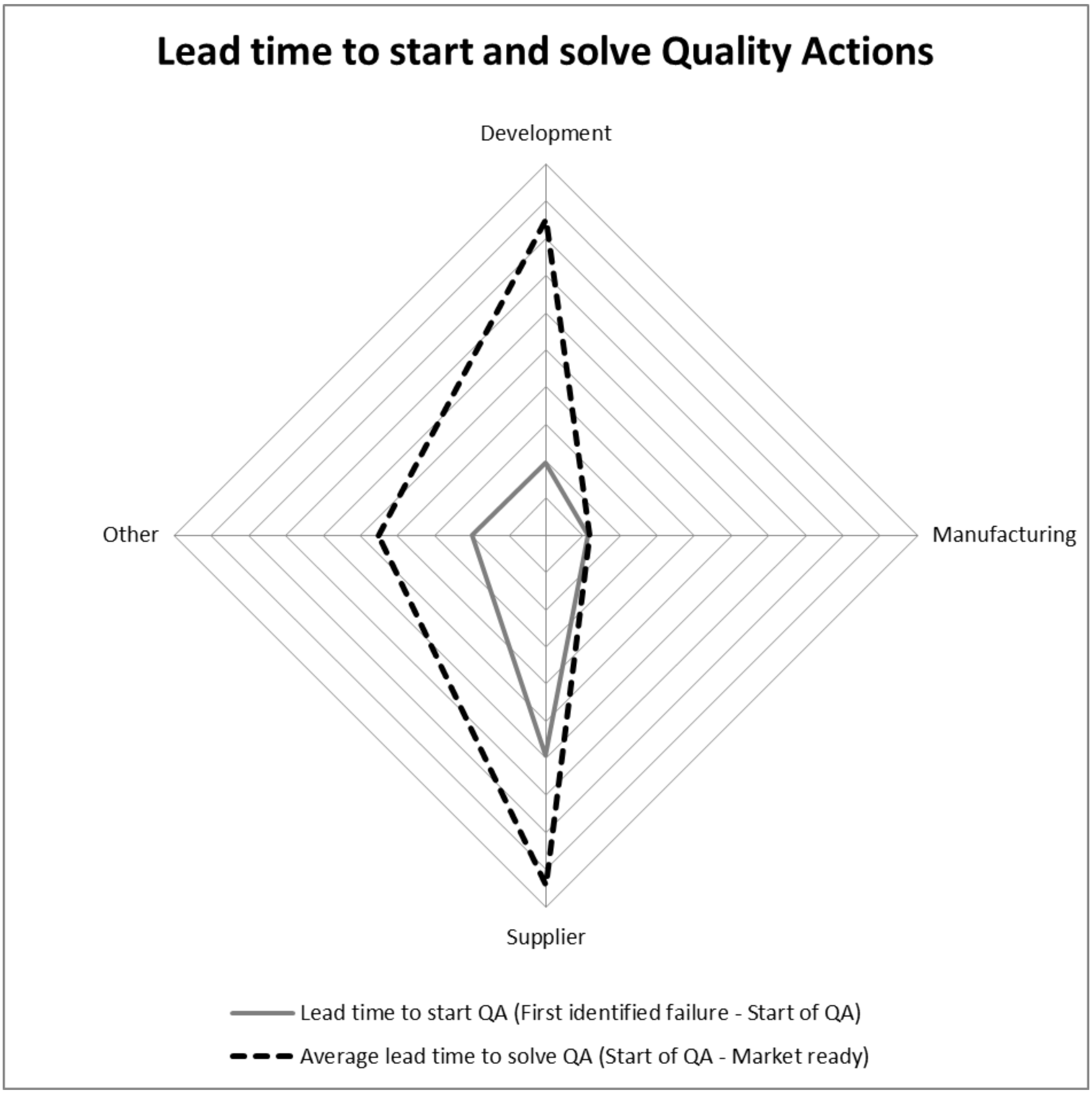


Figure 27, Lead time in number of days on the failure types

Figure 27 is visualizing Q&CS reactiveness to the customer's complaints and the four different axels are representing four of the failure types. The data used in the picture are all QAs started to enhance the new FH-series and are from January 2011 until May 2014. The graphs in Figure 27 only encounter QAs that have a first failure date, a start of QA date and a determined market ready date. The blue line in the graphs shows how many days in average it takes between first failure and start of QA and the green line shows the average number of days it take between start of QA and market ready date. There was some of the QAs that utterly affect the average of the population in respective failure type (e.g. Some of the QAs have started before the first failure is reported in and these QAs are assumed to be started with support of a PROTUS). QAs that stand out from the set are seen as outliers and removed from the population in the purpose of showing the normal case scenario.

Figure 27 shows that it takes longer time to identify supplier related failures, that the supplier and development related failures takes longest time in average to solve and that the manufacturing failures have a very short solving time. The manufacturing related QAs are to a large extent QSPs, which are, according to GTT, the fastest QA and it can be shown to be true.

The issues solved in a QA can be of very different characteristics why it can be hard to say anything about the efficiency or effectiveness in solving them. The way of identifying quality issues are on the other hand a more standardized procedure and it could be of interest to see how to shorten the lead time between identification of the first failure and start of the QA.

6.1.2 Evaluation of ITI's FF12 predictions within the New-FH series Project

This section analyzes how well ITI's RG model can predicts the failure frequency for trucks produced 12 months after start of production and when the truck has been out on the field in 12 months. This is done with GTT's forecast model which, in itself is evaluated with the use of earlier warranty data.

6.1.2.1 Analysis of the forecast model used within the maintenance organization

This analysis will examine the reliability of the forecast model used within the maintenance organization to estimate FF12 values from warranty claims, which uses earlier FF values such as FF9, FF6 and FF3. The analysis is done of two reasons, firstly to investigate if the forecast model is dependable enough to be used as an indicator of how the FF12 will progress during a peak period, as the maintenance organization uses it today. Secondly, since the true FF12 values for SOP+12 not will be available until 24-26 months after SOP, the forecast model will be evaluated to see if it can be used to validate the FF12 prediction for SOP+12 months made with ITI's RG model.

The analysis is made for historical FF values during both a stable and a peak period, since the authors expects the FF values to fluctuate more during a peak which would set tougher requirements on the forecast model. The FF values are cumulative and thus it can be assumed that it is the earliest, most immature, FF value that is least reliable to base the forecast on and thus it is only the FF3 forecast that is analyzed and not forecasts based on more mature values such as FF6 or FF9.

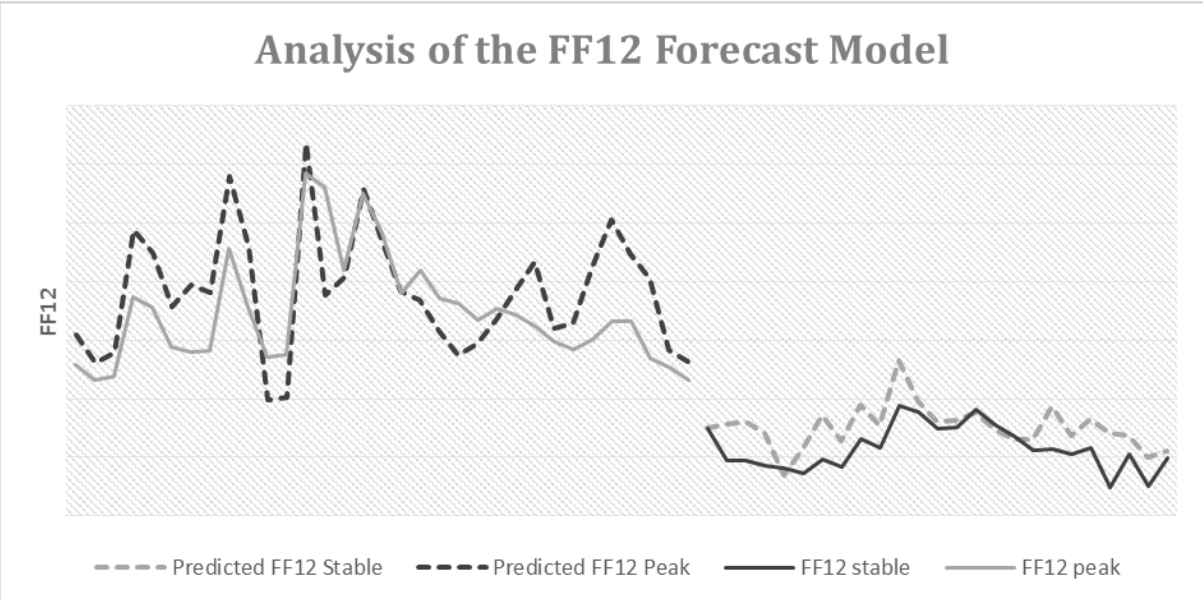


Figure 28, Evaluation of the Forecast model

Figure 28 shows how FF12 and the FF12 forecast based on FF3 differs during a peak period (to the left) and a stable period (to the right). The forecast follows the FF12 trend and the correlation between the lines in the peak period and the stable period are respectively 0,681 and 0,677 and the covariance for the respectively FF12 period is 0,165 and 0,024. This shows that the forecast follows the trend of the FF12 values well, but that the forecast made during the peak is fluctuating considerably more than the forecast made over the stable period. The forecast made within the peak period tends to overcompensate, for fluctuations in the FF3 value resulting in a larger fluctuation for the forecasted FF12 value than the real outcome. This creates more uncertainty about the forecasts within the peak period and it could be wise to consider this when the forecast is used to evaluate reliability progress in Q&CS maintenance organization.

The forecast prediction is however seen as reliable enough to be used in this thesis for validation of the predicted FF12 value at SOP+12 from ITI's RG model, especially since it is considered to lie within the end of the peak period or in best case even within the stable period.

6.1.2.2 Analysis of the discrepancies between the new FH-series' FF12 predictions and the FF12 values from warranty claims

In Figure 29 the ITI's RG model's FF 12 predictions made within the New FH-series Project are compared against the FF12 data from warranty claims. Since the FF12 values from warranty claims for the later months not yet were mature at the date for data collection, the FF12 predictions instead are compared against the forecasted FF12 values. According to the analysis above this assumption is considered to be valid and the forecast model will therefore be used to verify the accuracy of the FF12 prediction at SOP+12 due to lack of real FF12 values.

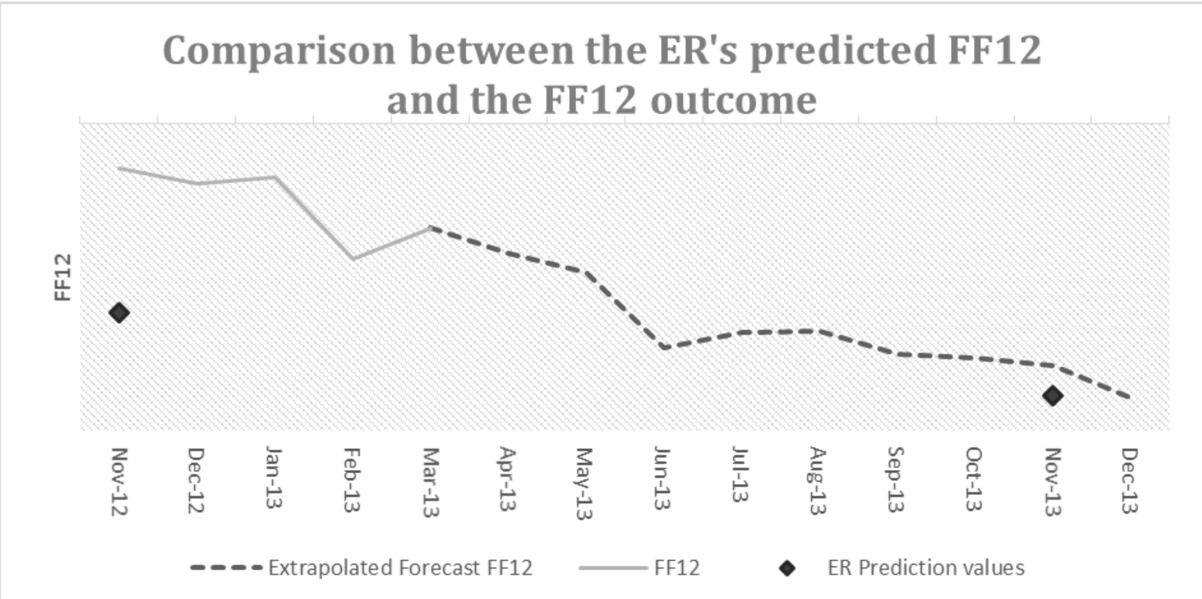


Figure 29, Evaluation of the predictions from ITI's RG model

The blue values in Figure 29 are FF12 values, the red values are forecasted FF12 values based on lower (mature) FF values and the green values represents the last predicted values from ITI's RG model. The ITI's RG model's FF12 prediction at SOP+12 seems to be more accurate than the value at SOP. Figure 29 clearly shows that the FF12 peak is underestimated by the project organization prediction made from ITI's RG model, but the predicted value at SOP+12 lies close to the forecasted FF12 from warranty claims.

6.2 QUALITATIVE ANALYSIS OF GTT'S ABILITY TO PREDICT RELIABILITY

This section combines the quantitative analyze with the literature framework and the situation assessment in the purpose of evaluating GTT's ability to predict reliability with the use of a RG-model.

6.2.1 Preconditions for reliability prediction within the New FH-Project

As described in section 5.2.1 *ITI's RG model*, the parameters within ITI's RG model are adjusted according to already performed development testing, in order to better reflect the real development process. In that sense, the prediction model will learn from the development process and be more accurate as the process proceeds. Thus, the amount of developmental testing is not only essential to identify and eliminate quality problems but also to ensure a more reliable prediction. The amount of developmental testing in the new FH-series project is the highest in any project at GTT and this has given good conditions for predicting future reliability, since it means a higher quantity of input data.

In one of the interviews with a reliability engineer, the necessity of understanding the customer needs in the developmental testing also was communicated. As seen in Figure 7, the customer needs is a source of variation affecting the design reliability of the product. Without understanding this variation reliable predictions cannot be assured, since the customer will use the product in another way then it is designed for leading to more or less warranty claims than expected. To be able to compare the reliability predictions for the different test phases and monitoring the reliability growth, the development testing also requires a standardized testing procedure between the different test phases. Changing the conditions would also decrease the trustworthiness of the predictions. However, the interviewee perceived the procedures for the developmental testing as extremely strict. The drivers performing the tests were professional drivers chosen to understand the customer needs and use the truck as in real life. Further reading about the testing procedures can be found in a press release from Volvo Group (Volvo Trucks, 2013). In addition to the strict testing procedures a well-functioning failure-reporting programme, referred to as FRACAS programme in the theoretical framework, is implemented to support the development testing. Hence, all failures are reported and stored in a database and review boards containing a reliability engineer and a

PMQ continuously reviews the failure reports and evaluate their severity as input to the reliability predictions.

Based on these facts GTT has the essential preconditions needed to perform trustworthy reliability predictions. In addition the project organization expressed a strong confidence in the trustworthiness of the predictions made from ITI's RG model and their ability to monitor reliability growth within the project process through the interviews, referring to the preconditions above.

6.2.2 Ability to predict FF12 at SOP+12

As mentioned in the theory, ITI's RG model's predictions is based on the failure report data from the developmental testing within the project development. By adapting the "Different notions of Product Reliability" (Prabhakar Murthy et. al. 2008), described in section 4.1, one of two conditions must be true for ITI's RG model to be able to predict field reliability.

1. The test environment during the developmental testing must take all existing variation within the truck's life-cycle in account.
2. The field reliability is equal to the design reliability, meaning that the truck's reliability is not affected by the variation existing after the design of the truck within the truck's life-cycle. This is also in this reports referred to as a stable product, or that the product has reached a stable condition.

Since, all variation is hard if not impossible to replicate within the developmental testing and the analyzed peak contained far from development failures (failures related to design reliability) only, it can be concluded that ITI's RG model not is capable of predicting the field reliability at SOP.

This insight is however nothing new for GTT, the project organization is aware of the tool's limitations and has therefore chosen to intentionally only include failures related to the trucks' design reliability. This means that the FF12 predictions only will be valid when the trucks have reached a stable condition.

By looking at Figure 29 the prediction at SOP+12 seems to be accurate. In addition by looking at the failure types pattern in Figure 25, failures related to variations after the design reliability within the product's life-cycle seems to continuously decrease radically up until SOP+12, being almost non existing. This can be seen since these failures in majority occur during 0-2 MIS and for the SOP+12 the amount of these failures are significantly reduced. At higher MIS the development failures seems to represent the majority of the failures, but these failures does not seem to decrease at the same degree. Together, it can be concluded that the peak at SOP+12 in majority contains of failures related to design reliability.

This finding together with the theory's definition of field reliability and the way GTT utilizes ITI's RG model it can be concluded that the New FH-series project reached a stable condition at SOP+12, mainly contained failures connected to design reliability, and that ITI's RG model is able to predict FF12 values for trucks within a stable condition, according to both the theory and the quantitative evaluation made within this thesis.

6.2.3 Ability to predict FF12 at SOP

As mentioned in the situation assessment section 5.2.2, to compensate for failures caused by variation after the design reliability within the product's life-cycle visualized in Figure 7, Visualization of design and field reliability (Adapted from Prabhakar Murthy et. al. 2008), the FF12 predictions from ITI's RG model at SOP are adjusted with a peak factor. Figure 29 shows that it was a significant discrepancy between the predicted FF12 value at SOP and the FF12 value received from warranty claims within the New FH-Project. By assuming, according to the analysis above, that ITI's RG model is capable of predicting design reliability it can be concluded that the discrepancy at SOP is caused by the peak factor's inability to compensate for the variation after the design reliability within the product's life-cycle.

Further evidence for this conclusion, is that interviews with a reliability engineer with high insight in the reliability growth prediction process and a quality range manager both revealed that the method for estimating the peak factor is not that extensively developed and lack any clear scientific evidence. As explained in the situation assessment the peak factor is estimated from the magnitude of a historical project's peak, with a relatively simple geometric approximation of the difference between the peaks' extremes and the stable FF12 value after the peak period. Thus, the approximation is not based on any deeper analyze of the actual reasons behind the reference peak. This implies that to provide as a proper reference for the new project's peak the historical project needs to be comparable to the new development project in terms of the factors below. These factors has been identified by the authors, as factors that should have a significant impact on the magnitude of the FF12 peak.

- Size and scoop of project
- Amount of new untested content
- Amount of development testing that is performed within the development project

- Resources available and their priority for reacting on the peak in the maintenance organization
- Amount of and level of reliability on content provided and developed by suppliers
- Amount of new untested processes in the manufacturing of the product
- Complexity of the manufacturing process
- Proportion of the product's sales in different geographical regions, since the tendency to claim a failure has been proven to differ depending on where the product is sold.

The situation assessment exposed that these factors are not given any further concern when choosing a reference project to estimate the peak from or that the peak factor itself is not adjusted with these factors in mind. This proves that there is plenty of room for improvement when estimating the peak, by knowing how these factors influence a project's FF peak and how to consider them when estimating the peak factor.

A drawback that has been identified of using a peak factor to adjust the FF12 prediction at SOP is that the magnitude of the peak factor often is relatively high, this means that small fluctuations within the predicted FF12 at SOP+12 will have a significantly higher impact on the predicted value at SOP. Hence, the SOP prediction will be significantly more vulnerable to small deviations within the predictions from ITI's RG model.

Besides from considering the factors mentioned above when choosing a reference project to base the peak factor on, it is also of interest to reflect upon the reference project's progression and how successful it was. This would have a high impact on the type of failures that arises on the market and their severity. For instance, in the new FH-Series project there were two module teams, *C* and *D*, that had a high impact on the peak's magnitude. The module teams where lacking in the development progress and did not have time to be development tested in the same amount during the project. This left several issues that still not was closed when the project was handed over to the maintenance organization. But, since these failures were expected to be solved before SOP+12, these failures were not taken into account for the FF12 prediction at SOP+12. To be able to cover the effect of these open issues when predicting the FF12 at SOP, they in somehow needs to be taken into account when the peak factor is estimated. To sum up, to be able to estimate a reliable peak factor there is a need to know the reference project's distribution of failure types and how the development project progressed in order to compensate for circumstances similar to module team *C* and *D* within the new FH-series project.

7 CONCLUSIONS

The advantage of using a RGM, to be able to predict future reliability growth, is reducing the risk associated with new product development significantly. But, beside from reducing the risk it also facilitates the development testing within the project process, since it is essential for the predictions validity. A well-functioning development testing process, with the ability to plan and track the reliability growth, will allocate the quality improvement work from the maintenance process to the project process, reducing the FF12 peak, and according to the theoretical framework reduce the cost of quality. The FF12 predictions made from ITI's RG model will never be exact, but the predictions is valuable as an indication of how the development project is progressing and what that will await the maintenance organization when the new truck is released on the market. Particularly valuable, when predictions made within the same project, at different periods of the development process, are compared against each other. This tells in what degree the reliability growth is expected to growth according to the project's trend. In addition the New FH-series project proofed that the RGM managed to identify and highlight the two problem areas within the project, at least 6 months prior to SOP according to the Engineering Reports. Evidently, there were not enough improvement actions taken to increase the development speed sufficiently to prevent failures from occurring in these areas on trucks on the market. The advantages related to the use of a RGM seems to be many and even if the FF12 values from warranty claims initially indicated of a more severe peak then predicted, without the use of RGM this peak would probably be even more extensive due to the large scope and the high degree of new content within the New-FH project. However, the peak has been reduced in a fast pace and everything speaks for that the FF12 prediction at SOP+12 will be reached. If this prediction could be more trusted within the maintenance organization, their work and resource allocation could be planned in a more efficient way.

The failure frequency peak in the new FH-series' was primarily driven by module team *C* and *D*. As mentioned earlier, this was expected by the project organization. The thesis made a brief overview of how the maintenance organization have prioritized their resources on respective module team, which showed that the resources was allocated with respect to the amount of warranty claims on these function areas.

To get a deeper understanding of what drives the height and width of the peak this thesis divided the warranty claims into failure types. The failure types are *Developmental, Supplier,* *Manufacturing, Customer Perception* and *Other*, which were decided upon through the interviews together with the theoretical framework. The analysis shows that the height of the peak is at first driven by the manufacturing failures, these failures primarily affect the field reliability of the truck according to the theory. In addition, the manufacturing failures occur in majority at the early MIS of a truck. The developmental and supplier failures take over as drivers of the peak's magnitude after the trucks reach three MIS, but also for later assembly months. The developmental failures can be categorized as designed reliability failures, the supplier related failures are harder to categorize due to lack of information about root-cause for the failures. The analysis of reaction time to start of a QA and the lead time for the QA reflects the failure types' impact on the width of the peak. The trend for the overall warranty claims shows that there is a reliability growth during the peak, and it can be seen that the manufacturing failures are the first ones to be resolved which is in line with the analysis of the failure types' impact on the peak's width. The developmental and supplier related failures takes approximately equally long time to solve but the supplier related issues takes a lot more time to identify. From this can be drawn that the supplier related failures have the biggest impact on the peaks width due to longest lead time and thus need more resources for resolution on the failing area.

The quantitative evaluation of the outcome of the FF12 predictions within the New FH-series Project clearly showed that ITI's RG model's predictions failed to predict the FF12 value at SOP. However the prediction at SOP+12 months lied within a satisfying range of the forecasted FF12 value. The qualitatively analyses also indicated that the predicted FF12 value at SOP+12 months can be used by the maintenance organization as an indication of the expected reliability at 12 months after SOP, when the failures related to child diseases are solved. Therefore, in future projects this value can be used as an indicator of how well the project is progressing and by the maintenance organization to plan for future resource utilization, when the project has reached SOP. Still, it must be remembered that the prediction never is an absolute number, but an indication of the outcome, with consideration to plenty factors within the project, the maintenance organization and the parameters within ITI's RG model used for the predictions. This means that the predicted FF12 values not are suited to use as a KPI, when evaluating the performance within the organization, but rather as a reliable target to work against, demanding that the preconditions for the predictions are transparent and well understood by both the project and the maintenance organization.

The qualitatively analyses of the predictions at SOP resulted in that GTT currently not is able to predict the FF12 value at SOP. The peak factor is supposed to compensate for the initial variation, while GTO is building up a stable assembly process, and as well as other unforeseen failures related to field reliability for the peak period. Since the FF12 prediction at SOP failed, while the prediction at SOP+12 was accurate, the peak factor was not capable of compensate for this variation. As the warranty claims within the peak for the reference project has not been investigated in this thesis, no conclusions can be drawn of the reasons to why the reference project's peak not is representable. However, several factors were identified that have a significant impact on the peak. These are not considered in any great extent when estimating the peak factor today; therefore it is of interest to further investigate how these factors impact the magnitude of the peak and how these can be compensated for when estimating the peak.

8 ADDITIONAL FINDINGS

As stated in the theory, almost all quality improvement actions are associated with lower cost on a long-term perspective and more and more manufacturers are aiming for a zero failure occurrence. The work with ITI's RG model within the project process is a proactive quality insurance process. With the use of RG planning, an intensive testing of the products and with RG tracking, a large portion of the time spent on failure resolution is relocated from the maintenance process to the development process. This decreases the total life time cost of a product thus a failures do not reach the customers and it is faster and easier to locate the root cause of the failure when the failure arise at a testing center. The RGM provides a good process where the RG planning sets the goal, the intensive testing identifies the failures and the RG tracking follows the progression towards the goal which leads to a high reliability focus within the development process. The RGM tool is proven to work successfully to proactively increase the reliability on the products. This is seen in earlier projects such as VCE, which received Volvo group's internal quality award for its success in reducing the peak by using the reliability growth process.

Volvo Group would benefit from a smaller peak and they would also benefit from a better reactiveness on the issues that drives the peak. This thesis has seen that there is a gap between the project organization and the maintenance organization within Q&CS and that the information channels between the two organizations have potentials to progress into a more effective one. The two organizations could both benefit from sharing the knowledge held within the two organizations. This thesis has three main areas that are of interest to further investigate for improvement.

The first area is to improve the communication early in the project process when the project organization decides upon the project scope and identifies the customers' needs. The project organization could benefit from the customer and field knowledge held by the maintenance organization, the maintenance organization has deep insights in these areas, received from real customer meetings and problem root cause analysis from earlier projects. If the information from maintenance organization can be transferred to the project organization in this early phase of the project process it would give the project organization a better starting point and a better project scope. This is also in line with Bergman and Klefsjö's (2010) relative cost of change concept.

The second area is to transfer the PROTUS data with claims from the project organization to the maintenance organization during the handover phase. The maintenance organization is constantly working with massive amount of data and is more than qualified to data mine in these failures. The failures that are reported as PROTUS can happen out in the field due to tougher environment, careless usage from the customer or due to mistakes made in the project organization. Two suitable meetings have been identified where the PQL and the PMQ can exchange information face to face. Firstly the handover meeting, the second one is when the project organization sorts out which failures that should be included in the RGM calculations. The second meeting is not a meeting where the maintenance organization have been involved in previous projects, but a PMQ suggested during an interview that it would be of benefit for both organizations to take part of this meeting. The maintenance organization receives knowledge regarding what types of failures that are caused in connection to their module team and both the project and the maintenance organization gets a better categorization of the failures, which leads to a better prediction in the end.

The third area is regarding management of the peak. Deming points out that the reliability assurance not is a specialist function and to be able to continuously improve the reliability of a product the work needs to be done cross-functionally between all functions in the company. Because of this, the creation of reliable product is primarily a management task (Deming 1988). A potential action to get both awareness and to reduce the impact of the peak is to appoint a manager who takes responsibility of the peak and continuously work to reduce both its width and height. This manager can build up a expertise in what drives peaks and how to reduce them, for example make sure that supplier relations are tight and that the manufacturing process are ready for SOP.

9 DISCUSSION

An obvious area of discussion is the thesis capability of generalizes its results upon a general major development project at GTT, or even of more interest a general major project at a global truck manufacturer. To be able to evaluate GTT's ability to predict the peak it requires that the peak in the case project is representative for the average project at GTT, which cannot be guaranteed since the thesis only investigates one specific peak and has nothing to compare the results with. Therefore this has to be assumed in order to be able to draw any general conclusions at GTT. The extensive workload associated with the data mining and with the definition of the thesis' purpose, due to the initial problem's open nature, did not allow to include more than one case project into the thesis' scope. Thereby, it could be interesting to embrace the study's elaborated methodology and use this on other projects at GTT. This could hopefully give further proof for the thesis' findings and allow drawing more generalized conclusions.

10 RECOMMENDATIONS

Besides from being able to predict the field reliability for a stable product already within the project process, the extensive development testing programme that the RG methodology induces, if being used properly, also transfers an essential share of the problem solving of reliability related issues from the maintenance process to the project process. This results in a reduction of the cost of quality improvements, increases the customer satisfaction and ITI's RG-model has shown, in the New FH-series project, to have the ability to predict the products design reliability, i.e. FF12 for a stable product, which is of high value for the maintenance organization. Therefore, it is highly recommended for Volvo Group to continue working with ITI's RG model and focus on conducting a high degree of developmental testing within the project process.

The major obstacle when predicting field reliability for Volvo Group today is to find an appropriate way to compensate for the variation existing early after market introduction when the product still not has reached a stable condition. The way it is performed today, by using a peak factor, has no scientific verification and there are more aspects to consider than just the similarities between the projects extent and scope. Here, the progression and outcome of the reference project's developmental process, the amount of developmental testing within the reference project, the distribution of failure types within the reference peak and the resources assessed to react on the reference peak would be of high interest to consider. It is therefore recommended to further investigate how the peak factor can be chosen in a better way to better fit the intended new development project, as a recommendation these factors could be interest to consider initially.

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