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Failure handling in product development

A study within Volvo GTT Powertrain Engineering

Master of Science Thesis

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Abstract

In product development where prototypes are built and tested, identified failures must be addressed somehow. This thesis examines the PROTUS process, a failure-reporting process employed at Volvo GTT Powertrain Engineering in order to report and correct deficiencies in the prototypes. This study brought further insight to existing literature on FRACAS (Failure Reporting And Corrective Action System) processes, quality and process measurements in order to fulfill the purpose of designing a process for reporting, using and following up on prototype failure data in a way that enables continuous improvement in the product development process. The study was conducted through action research in which the researchers assumed central roles in the process, followed by interviews with employees. In total, seventeen semi-structured interviews were conducted with engineers and managers who are connected to the PROTUS process. The interviews resulted in a better understanding of the process, including its strengths, weaknesses and improvement opportunities.

Lessons learned from the study include that improvement and organizational learning do not occur automatically, and that the potential for learning will not be fulfilled if there is no outspoken demand. Further, it is shown that process measurements focusing on the number of open failure reports and failure report closures per week can result in insufficient problem investigations. As for the reporting of failures, it is concluded that there should be clear guidelines for what to include when reporting and that the input to the process is pivotal.

Keywords: Failure reporting, failure handling, FRACAS, root cause analysis, corrective actions, quality, learning, automotive, measurements.

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Carl Magnus Gustafsson and Joacim Ullberg

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List of abbreviations

Abbreviation:	**Explanation**:
3C	Volvo's tool for problem solving, similar to the PDCA-cycle (Plan Do Check Act)
CPM	Chief Project Manager
CW	Closure Week
CTQ	Critical To Quality
DCN	Design Change Notice
DTL	Daily Team Leadership: Reoccurring group meeting held once or several times a week.
DVG	Design and Verification Guidelines
GDP	Global Development Process
GTO	Group Trucks Operations
GTT	Global Trucks Technology
GTT PE	Global Trucks Technology Powertrain Engineering
GTT VE	Global Trucks Technology Vehicle Engineering
KOLA	Konstruktionsdata Lastvagnar, Swedish for Design data Trucks:
KPI	Key Performance Indicator
PE	Powertrain Engineering
PI	Performance Indicator
PLV	Project Leader Verification
PM	Project Manager
PME	Project Manager Engineering
PMO	Project Manager Operations
PMQ	Project Manager Quality

PROTUS	PROTotypUppföljningsSystem, Swedish for PROType follow-Up System
PTM	PROTUS Team Meeting
RC	Root cause
RCA	Root cause analysis
SR	Solving Responsible
VE	Vehicle Engineering
QJ	Quality Journal

Part I: Introduction

"If you want to succeed, double your failure rate"
Thomas J. Watson

This chapter introduces the problem background, describes the purpose of the thesis and presents the research questions. The chapter is concluded by providing a disposition of the thesis outline, to provide an overview of the structure of the thesis and the content of each section.

1 Introduction

1.1 Background

On the path to improve quality comes the need to avoid faults and to prevent potential faults from occurring, based on the assumptions that these faults incur a cost for the organization in the end (Bergman & Klefsjö, 2010). This cost related to poor quality can take many forms and shapes, many of which are described as hidden costs and therefore often difficult to identify (Harrington, 1999). Cost of poor quality can include cost for rework, damage to the customer relationship, maintenance costs, and excessive inventory among others (Bergman & Klefsjö, 2010; DeFeo, 2001). Therefore, it is simply not enough to just be aware of these issues, and while being one step on the path to achieve higher quality, awareness alone will not allow an organization to become a leader in quality (Bergman & Klefsjö, 2010). Therefore an organization has to actively work on improving the reliability of their processes, products and services through preventive and corrective actions (Bergman & Klefsjö, 2010).

Even while preventing the faults from occurring in the first place and striving to do things right the first time is commendable, not all faults can be prevented. Nor is it always desirable (Thomke & Reinertsen, 2012). Constraints such and limited resources and high complexity result in scenarios in which not all faults can be prevented just trough preventive actions with methods such as FMEA (Failure Mode and Effects Analysis) (Carlson, 2012) and VMEA (Variation Mode and Effect Analysis) (Johanesson, et al., 2012). Therefore mechanisms and processes are needed to ensure that faults that in fact do occur are dealt with in an effective manner, including both action for correcting the fault, and ensuring that actions are taken so that its reoccurrence can be prevented (Department of defense USA, 1985).

Motschman and Moore (1999, p. 164) define corrective action as: *"[…] the action taken to eliminate the causes of an existing nonconformity, defect, or other undesirable situation in order to prevent recurrence"*. Literature describes general principles for, and guidelines on, how such systems and processes for fault correction could be configured, including failure correction system theories such as FRACAS (Fault Reporting Analysis and Corrective Action System) (Department of defence USA, 1985; Hallquist & Schick, 2004; Motschman & Moore, 1999; Lee, Chan, & Jang, 2010). The literature related to this field also describes methods and theories on how the problem cause should be investigated and handled, commonly referred to as RCA (Root Cause Analysis) (Vanden Heuvel, et al., 2008; Bhaumik, 2010). This literature often deals with these issues on a general aggregated level and therefore a case study could provide feedback of the applicability of these theories and generate valuable insight into how failure reporting is conducted in a more specific case.

This thesis builds upon a case study at Volvo Group Trucks Technology Powertrain Engineering Göteborg (GTT PE GOT). At Volvo a formal procedure for failure reporting known as PROTUS (**PROT**otyp**U**ppföljnings**S**ystem, Swedish for **PROT**otype follow-**U**p **S**ystem) is currently in use to handle failures and nonconformities that occur during product development of new or existing products. This process is in many ways similar to the FRACAS process mentioned in literature and as such represents an opportunity to study and investigate how the Volvo process works in relation to existing theory in the field of failure reporting. Since the PROTUS process is used during prototype test runs in the product development phase this study could help to deepen the understanding of corrective actions taken during the product development phase, including the conditions and the needs for such processes as well as how they compare to existing theory.

Volvo GTT PE is a global organization responsible for developing heavy engines, gearboxes and axles for AB Volvo. Today, they believe that there is potential in improving PROTUS process and how they store and use the data in PROTUS, particularly the qualitative data. Volvo aims to do so by enhancing the way of storing and analyzing the data and by developing appropriate performance measurements on which decisions can be based in order to improve quality and reduce development times. They furthermore, wish to achieve more learning from the PROTUS process and not just correct errors for the time being. This makes GTT PE an appropriate organization to study for research on how to improve failure reporting and corrective action.

1.2 Purpose

The purpose of the study is to design a process for reporting, using and following up on prototype failure data in a way that enables continuous improvement in the product development process.

1.3 Research questions

In order to meet the purpose three questions guided and provided focus for the research:

- How should the process for using reported prototype failures in a product development environment be designed?
- How should failure data be reported to support improvement?
- How can performance indicators be used to follow up the process for handling reported prototype failures and how can they be used to facilitate improvement?

1.4 Delimitations

Due to the time required to implement the results of this study, implementation of results was not included in the scope. The study is also geographically limited to the

Swedish GTT PE branch although the PROTUS system is used throughout the Volvo Group.

This study focuses on the failure reporting process and therefore other parts of the PROTUS system are not covered, such as deviation reports, cost improvement projects and prototype structures that also are contained within in the PROTUS system.

1.5 Thesis outline

Part II: Methodology
The methodology chapter describes how the research has been conducted, including the research methods used along with how the data have been collected and analyzed. Additionally it explains how the issues of validity and reliability have been addressed.

Part III: Theoretical Framework
This section provides the reader with the theory used in the analysis of the findings. This theory is built upon several areas including basic quality management, theories about learning on an organizational level, methods for investigating and correcting faults, process management theory and theory about measurements.

Part IV: Empirical Study
In the empirical study section the findings from the observations and from the interviews which are relevant to the research questions and for the recommendations are presented.

Part V: Analysis
In this chapter an analysis of the case is presented, divided into three parts starting with the Principles, followed by Practices and Tools. The Principles part contains the analysis of why things are done including the goals and objectives for the PROTUS process. The Practices part concerns the process and what is to be done and finally the tools part addresses the tools used in the process, including an analysis of supporting systems and measurements.

Part VI: Discussion
In the discussion section the results from the analysis are discussed and reflected upon.

Part VII: Conclusions
Here the findings drawn from the analysis and answers to the research questions are presented. Moreover areas appropriate for further research are discussed.

Part VIII: Managerial Implications
This section presents suggestions on what Volvo can do in order to improve the PROTUS process and to enhance their learning capabilities from the process.

Part II: Methodology

"By what method? ... Only the method counts"
W. Edwards Deming

In this chapter the methods that that have been used in the study are presented, including research strategy, data gathering methods, data analysis and how the concerns regarding validity and reliability have been treated.

2 Methodology

2.1 Research strategy and design

The research consisted of a study of a single organization utilizing both qualitative and quantitative data, i.e. a case study of the PROTUS database and the processes surrounding the system including how data are stored, used and analyzed. Emphasis is put on the qualitative findings. The study was constructed as action research and the majority of the research was conducted on-site, benefiting from direct access to the system, observations, as well as comments from employees. The definition of action research is not completely agreed upon, however psychologist Kurt Lewin, who argued for a research discipline aiming to help the practitioner (Lewin, 1946), had the notion of *"…a way of learning about a social system and simultaneously trying to change it"* (Gummesson, 2000, p. 117), and Lewin was of the opinion that if one wants to truly understand a phenomena, one must try to change it (Kaplan, 1998). This action research was conducted through assuming the roles of PROTUS process coordinators in a major project during the first three months of the study, which entailed frequent contact with the users and managers of the process. A PROTUS coordinator is responsible for monitoring failure reports in a certain project and sees to that the reports are updated and filled in correctly. The role also includes inviting engineers responsible for resolving the issues to meetings with managers from the project and chairing these meetings. In this project the role as PROTUS coordinators allowed for daily contact with the project management team as the positions were co-located.

A difference between action research and general qualitative research is that the boundary between participants and researchers are blurred, where the research is conducted in collaboration, and more stress is put on actionability, meaning that the knowledge gained should be usable by all parties (Shani, Albers Mohrman, Pasmore, Stymne, & Adler, 2008). Benefits from using action research as opposed to common qualitative methods include being able to get a better pre-understanding through firsthand experience, which also lets the researcher access matters that otherwise would be unspoken, and also that when a researcher partakes in the process, generated theory can be tested in action and modified in action (Gummesson, 2000).

The study followed the steps of qualitative research presented by Bryman & Bell (2011), where research questions are constructed initially, followed by selection of relevant sites and subjects. Thirdly, data were collected which were interpreted and resulted in a conceptual and theoretical framework. Subsequently the collected data were further interpreted after which additional data were collected. This non-linear abductive approach, where the researchers go back and forth between theory and empirical findings in an inter-twined process is referred to as Systematic Combining by Dubois & Gadde (2002) when it is applied on a case study.

2.2 Literature study

An initial literature review was conducted in order to create the theoretical foundation on which the study is built. Bryman & Bell (2011) claim that a literature study provides a basis on which the research design is built and guides in gathering and analyzing the findings. This review covered areas such as continuous improvement, feedback processes, process analysis, process improvement, general quality areas and performance measurements, and further literature was gathered as phenomena were revealed during the course of the study. The literature was found using Chalmers Library, Google Scholar, Volvo Library and by backtracking references from relevant articles. Some keywords that were used when searching, both one by one and in various combinations were: *Failure reporting, failure reporting and corrective actions, failure reporting systems, quality, FRACAS, processes, KPI, performance measurements, root cause analysis, improvement, indicators* and *learning*.

2.3 Data collection

The collection of empirical data was conducted on the basis of triangulation. This was done as the accuracy of judgments can be improved if different kinds of data are gathered concerning the same phenomenon (Jick, 1979). In addition to reliability and convergent validation, triangulation can provide a more holistic portrayal of the studied object or organization than what would have resulted from a single method study (Jick, 1979).

The data collection process consisted of two parts. Firstly, in order to create an understanding of the current state of the process, i.e. how it is used and its possibilities and limitations, action research was conducted where observations were made when assuming the roles of PROTUS coordinators. Subsequently a series of interviews were conducted with several employees from Volvo GTT PE who are involved in the PROTUS failure reporting process, as well as the persons responsible for the PROTUS system. The PROTUS system and its database were also examined throughout the study in order to understand the contents and structure. Furthermore, data in other databases or documents were used.

2.3.1 Action research

When assuming the roles of PROTUS process coordinators, observations were made while acting as participant-as-observer, during which the members of the setting were aware of the researchers being researchers while fully participating (Bryman & Bell, 2011). Non-participative observations were also used when meetings were attended in projects in which we had no influence. Notes were taken on each meeting that was attended by using jotted notes, and a journal was kept throughout the course of the study where impressions and observations were written, which at the end of each week was reviewed and summarized. During the initial phases of the study, focus was on finding answers to what and how things were done, as well as why and if there were any anomalies.

2.3.2 Documentation

According to Bryman & Bell (2011), documentary sources can provide valuable information on how a company works. In this study several types of documentation at Volvo were used. PROTUS manuals were initially used in order to provide insight in the systems and the process and later compared to how well they represent the current way of working. PROTUS audit presentations were used to provide information on the efficiency of the process, and PROTUS reports were examined to give information on how faults are reported and addressed. The documentation was found through the PROTUS system and by searching on Volvo's internal network.

2.3.3 Interviews

Unstructured interviews were conducted in the shape of regular improvement discussions as a natural part of the action research, as well as spontaneous discussions with employees. Adding to these, seventeen semi-structured interviews where interviews are guided using a set of pre-determined questions (Bryman & Bell, 2011) were conducted with employees who were selected from a range of employees who were responsible for the PROTUS process, employees who used it or such that in any other way were affected by it. Finding interviewees in different positions was stressed during the sampling in order to provide views from as many perspectives as possible, aiming at creating holistic insight into the process. The questions asked during these interviews were gathered in an interview guide beforehand, where different guides were constructed for managers and engineers assigned to be responsible for the reports. The questions in these guides were based on the researchers' own observations during the action research process as well as findings from the literature study, and they were validated by asking a person from each interviewee category if they understood all questions. The lengths of the interviews ranged from twenty minutes to two hours, and were held with one interviewee at a time in a setting where none other than the researchers could hear the answers. However, most interviews lasted for more than one hour. The sessions were audio recorded in order for the researchers to be able to listen to the interviews afterwards and analyze the answers, and the researchers took notes. Directly after each interview, the sessions were discussed and the recordings were analyzed and summarized.

2.4 Data analysis

Qualitative methods were used to analyze the data stored in PROTUS and the interviews in order to examine and understand the system and identify areas for improvement. The analysis started off with mapping the current process based on observations, which Damelio (2011) considers to aid in analyzing a process, and then detailed analysis of where and why matters are the way they are after interviews had been conducted . Bryman & Bell (2011) claim that coding is a key process done directly after the collection of data, which Denscombe (2003) operationalizes as breaking down units of the data and categorize them. This was done after the interviews where the answers and statements were categorized into themes and written down on notes that were put on a wall, clustered in the different themes. Process maps were constructed based on the empirical findings and shown to employees with knowledge of the process in order to verify them.

2.5 Validity and reliability

Reliability can be divided into internal and external reliability. According to Bryman and Bell (2011) the internal reliability in quantitative research is related to how well in the case of more than one researcher the researchers agree on what they observe, while the external reliability concerns the degree that the study can be replicated. The replicability of this study is likely to be low, since it is a case study and since the social setting in which the research took place is not static and therefore subject to change (Bryman & Bell, 2011).

The internal validity concerns the issue of how well the researchers' observations and the theory that is developed based on these observations match. The internal validity is often debated in action research as with the risk of going native (Bryman & Bell, 2011). As a means of securing the validity, triangulation was applied in this study, where not only interviews and observations were used as a basis for analysis, but also quantitative data from the PROTUS system. While not eliminating the reliability risk, it should help reducing it. When working closely with a study object, researchers risk going native, meaning that one can lose sight of the objectives and position as a researcher, and start possessing the view of the ones being studied (Bryman & Bell, 2010). Gans (1968) set up three levels of participant observer roles, consisting of total participant, researcher/participant and total researcher, ranging from completely native to completely detached. Usually a researcher transcends between two or three levels throughout the study (Gans, 1968). The triangulation was important since the role as total participants while providing rich insight into certain parts of the process and workflow did not provide deep insights from all points of view, and therefore the interviews were constructed to provide a complementing view of the process.

The external validity concerns how well the findings can be generalized and although a study of a single organization is related to risks of providing low external validity (Bryman & Bell, 2011) and that a common mistake in case studies is to try to describe everything and thus end up describing nothing, Dubois & Gadde (2002) claim that such a study can provide means for utilizing in-depth insights to develop theory from empirical data, and that the risk of trying to cover more areas than manageable is kept low by being parsimonious, i.e. selective about what to include and making the report coherent. Performing a case study was deemed to be the most appropriate way of working since an overall understanding facilitated the possibility of answering the research questions which concern a complex process for which such contextual understanding was pivotal, and a study of several sites would have provided less time to address each of the sites. Additionally the validity was secured through the use of reflexivity which entails active engagement of critical self-reflection on potential biases (Johnson, 1997).

Part III: Theoretical Framework

"Experience without theory is blind, but theory without experience is mere intellectual play"
Immanuel Kant

This part contains the results from the literature study which lay the foundation for the analysis. The main focus in this chapter lies on quality management and the essential fundaments needed for a process to support and develop customer satisfaction.

The building blocks needed for a process that aims at taking corrective actions toward a specific fault as well as the common issues often faced with such processes and how to overcome them are also described.

3 Theoretical framework

When the theory was collected for this framework it was regarded to be covering three different levels of abstraction; Principles, practices and tools. The underlying quality management principles influence all aspects of the process, in which practices are conducted, i.e. what is done, and tools are used in order to aid in conducting the practices. For practices, FRACAS theory was attended combined with general process theory and theory about learning and RCA. On the tools level there is theory on performance measurements. Figure 1 illustrates the framework used in this thesis to structure the theory and the analysis. In each area shown in the figure some of the different theoretical findings are listed in their related area together with their references.

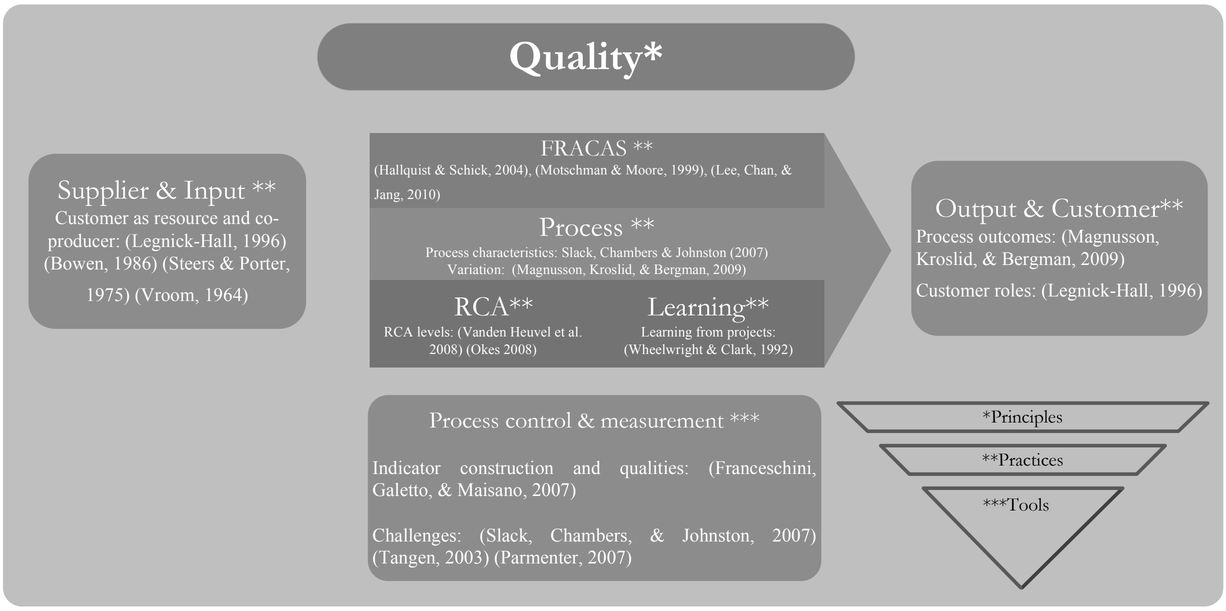

Figure 1. Theoretical framework

3.1 Quality management

Quality is a term of which it is hard to find a definition that everyone can agree on. Joseph Juran (1951, pp. 2-2) defined it simply as "*fitness for use*", similar to Philip Crosby's (1988, p. 27) "conformance to requirements" definition, whereas Genichi Taguchi presented a wider definition which sees the absence of quality as the losses a products imparts from society from when it is shipped (Taguchi & Wu, 1979). Walter Shewart considered quality to consist of two dimensions where one is measurable and the other is subjective, depending on how the customer experiences the product (Bergman & Klefsjö, 2010).

Total Quality Management (TQM) is a holistic framework for continuously improving quality in an integrated fashion (Bergman & Klefsjö, 2010), which Bergman & Klefsjö (2010, p. 37) more clearly define as "*a constant endeavor to fulfill and preferably exceed, customer needs and expectations at the lowest cost, by continuous improvement* *work, to which all involved are committed, focusing on the processes in the organization"*. TQM is described as being based on six values, which Bergman & Klefsjö (2010) represent with the cornerstone model, Figure 2. This model constitutes a basis for the theoretical framework of this thesis.

Figure 2. The cornerstones of total quality management, adapted from Bergman & Klefsjö (2010, p. 38)

Focus on customers, the first cornerstone, is a central aspect of quality as it concerns finding what the wants and needs of the customer are and fulfilling these. This cornerstone applies to internal customers as well as external ones, meaning that not only the end customer should be considered, but also employees within the company (Bergman & Klefsjö, 2010). Practicing an internal customer-supplier concept, where the internal customers' requirements are identified and self-inspection and control is carried out before passing the product or service on, is supported by Dale (2003) as a method for communicating the need for continuous improvement. In order to maintain a focus on the customer, Juran & De Feo (2010) suggest that setting specific goals for customer satisfaction is an appropriate mean.

For a failure reporting system that shall enable continuous improvement, there are multiple customers requiring different performances, e.g. knowledge or an improved product. Legnick-Hall (1996) presents theory regarding customers' roles through describing five different ways in which a customer can contribute to quality. Customers could contribute as a **resource**, by giving knowledge, capital, resources or ideas for example. For this to be fruitful, the information must be useful and understood by the producer, and the producer must be able to act upon the input. The customer could also contribute as **co-producer**, which is most common for industrial customers, where they can influence the product design, production scheduling and deliveries. This is particularly important when there is a link between quality and customization. Three prerequisites for such co-production are clarity of the task, ability to do the work and motivation to do the work (Bowen, 1986; Steers & Porter, 1974; Vroom, 1964). The customer can also give input as a **buyer**. Lengnick-Hall (1996) suggests that external communication with buyers can augment companies' reputations and the competitive quality, and by fostering trust and interdependencies, relationships can be created which enhance the quality of the system. Customers of large quantities will often have more influence than those of small quantities on the company (Legnick-Hall, 1996). Customer as a **user** can be utilized in quality efforts by examining user reviews and identifying user satisfaction, thus pointing out quality gaps (Legnick-Hall, 1996). This gap can be comprised by differences in user expectations and experiences and can be handled by carefully signaling what to expect (Legnick-Hall, 1996). The customer can also have the role of a **product**, in that the customer is in some way transformed by the supplier, where Lengnick-Hall (1996) proposes that the experienced quality of a good or service is linked to the customer's motivation to change as a result of the purchase, and also that the satisfaction is positively linked to the customer's likelihood of changing as a result of the product's or service's use.

The second cornerstone, ***Base decisions on facts***, states that decisions should be based on facts and not random factors. One of the reasons to why products might fail is that the company has insufficient actual knowledge about the product (Bergman & Klefsjö, 2010). In order to be able to base decisions on facts, information must be gathered, structured and analyzed (Bergman & Klefsjö, 2010). Performance measurements as basis for decisions on how to improve a process and root cause analyses which enable corrective actions are both relevant to this cornerstone and are addressed later in the report in chapter 3.5 and 3.6.1 respectively (Franceschini, Galetto, & Maisano, 2007; Bhaumik, 2010).

The third cornerstone is ***Focus on processes***. Processes are what constitute most organized activities which transform input into output to a customer (Bergman & Klefsjö, 2010). In order to minimize the required resources and create customer satisfaction, it is important to identify the suppliers of the process and provide what is needed to support the relationships and tools (Bergman & Klefsjö, 2010).

Improve continuously is the fourth cornerstone, and according to Bergman & Klefsjö (2010), you stop being good unless you keep improving, and there is always a way to improve quality by using less resources (Bergman & Klefsjö, 2010). One must accept that mistakes are made and utilize them as an asset on which improvement can be made by learning from them, and not focus on finding scapegoats (Bergman & Klefsjö, 2010). The purpose of this thesis includes the enabling of continuous improvement in the product development process, which we link to organizational learning. He, Qi & Liu (2002) argue that in order to maximize improvement work, quality tools need to be integrated in the organization.

The fifth cornerstone is ***Let everybody be committed***. Participation and conditions that enable it are essential in order to achieve continuous improvement. In order to facilitate this, communication, training and delegation are important factors, which should be combined with employees taking responsibility. People who are given the chance to perform well and get recognition when doing so will be committed to their job (Bergman & Klefsjö, 2010).

The final cornerstone, ***Committed leadership***, should be practiced on all levels in an organization in order to create a culture for quality improvement (Bergman & Klefsjö, 2010). Joseph Juran supports this notion by telling that "*To my knowledge, no company has attained world-class quality without upper management leadership*" (Bergman &

Klefsjö, 2010, p. 48). The committed leadership is however not only based on personal commitment but also visibility and clarity in the organization (Bergman & Klefsjö, 2010).

3.2 Performance dimensions in operations and quality

Skinner (1966) presented the concept of trade-offs in performance objectives, suggesting that companies must decide on what strategy to implement to reach desired qualities in selected dimensions related to their operations performance. This concept has, however, been challenged and authors have argued that there is a way to achieve performance in multiple dimensions without sacrificing others. Ferdows & De Meyer (1990) presented the results from a survey showing companies that performed in several, if not all, performance dimensions. They suggest that companies can apply a so called *sand cone model*, depicted in Figure 3, which they build upon Nakane's (1986) findings which suggest that Japanese companies who offer flexibility successfully have all at first achieved a minimum level of ability in quality, dependability and cost. Ferdows & De Meyer (1990) argue that quality improvement is the basis for all improvement and that this can lead to simultaneous improvements in the other dimensions. This differs from Nakane's (1986) view in that cost improvement is the ultimate result of performing well in the lower layers of the sand cone, rather than being a prerequisite for flexibility. Nakane (1986) and Ferdows & De Meyer (1990) also both deviate from Skinner's (1966) view of quality being merely one of the performance dimensions.

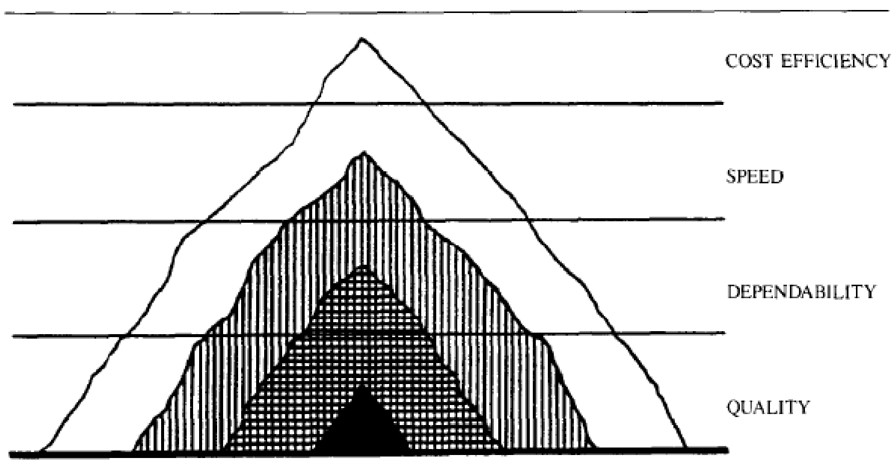

Figure 3. The sand cone model as presented by Ferdows & De Meyer (1990, p. 175)

For service and product quality the quality concept can be divided into several quality dimensions. According to Bergman & Klefsjö (2010), there are eight dimensions of quality for goods, and eight for services. For goods, the dimensions presented are *reliability, performance, maintainability, environmental impact, appearance, flawlessness, safety* and *durability.* Services differ from goods and require different qualities, for instance are they not as tangible and it can be harder to measure their contents (Bergman & Klefsjö, 2010). The quality dimensions of services provided by Bergman & Klefsjö (2010) are *reliability, credibility, access, communication,* *responsiveness, courtesy, empathy* and *tangibles.* Mohammad (2010) combines traditional quality dimensions of goods and services into a framework for those in knowledge management systems, and sets up various dimensions for each part of such systems. A knowledge management system is according to Jennex (2005) defined as "*a system that is created to support the capture, storage, search, retrieval, and application of knowledge*". This framework is presented in Table 1.

Table 1. Quality dimensions and their corresponding characteristics for KMS, as presented by (Owlia, 2010, p. 1223)

Dimensions	Characteristics
Functionality	Meeting organizational objectives Satisfying users' needs System usage Providing primary (core) knowledge Providing primary functions including knowledge creation, storage retrieval, distribution, and application
Completeness	Providing supplementary (advanced, innovative) knowledge Providing supplementary / more advanced functions and technologies e.g. artificial intelligence or expert systems Meeting established software, hardware, and communication standards
Reliability	Accuracy Fault free Consistency Currency Credibility, trustworthiness Legacy
Usability	Easy to use Friendliness Training, learnability Appearance Communication, knowledge conversation and sharing
Serviceability	Personalization Customization Handling users' enquiries Solving system problems Responsiveness, how well a KMS responds to demand by users.
Access	Accessibility Availability Response time Timeliness
Flexibility	Flexibility Compatibility Interoperability Scalability Future-proofed
Security	Security Privacy Control

3.3 Learning from mistakes

Love et al. (2005, p. 1) describes the field of knowledge management (KM) as: *"[…] the process of creating value from an organization's intangible assets"*. While knowledge according to Davenport & Prusak (1998, p. 5) can be defined as: *"[…] a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating new experiences and information"*.

A framework for how the area of knowledge management can be conceptualized is given by Love et al. (2005). The idea here is that as data become processed they are turned into information. The information is turned into knowledge when the information has become actionable and as the knowledge becomes learned the value of the knowledge increases for the organization (Love, Fong, & Irani, 2005). The motor for this process is the organization's ability to learn. This knowledge cycle is affected by environmental factors including the domain context of the data, the organizational culture and value system, benchmarking and standards and finally the management initiatives as such these are the governing variables that affects the organization's ability to generate knowledge.

Love et al. (2005) state that there are three major components that affects how well a knowledge management strategy performs, the people, the process/culture and the technology. The people are the ones that will participate in sharing and receiving knowledge and the right incentives are needed in order to motivate this sharing. The right processes and culture ensures that the sharing of knowledge is built into the structure of the company and becomes a part of the daily activities and the Technology enables the sharing of knowledge. Love et al. (2005) argue that knowledge can be gained both from failures and from successes and as such both failures and successes should be stored as lessons learned in order for this knowledge to be internalized.

3.3.1 Organizational learning

The learning organization is considered an important notion by several authors including Bergman & Klefsjö (2010), Garvin (1993), Robbins & Judge (2010) and Wheelwright & Clark (1992). The ability for an organization to act and to adapt to changes in a dynamic and complex environment is directly dependent on an organizations ability to learn or as Kim (1993, p. 37) puts it: "*All organizations learn, whether they are consciously choose to or not-it is a fundamental requirement for their sustained existence*". This ability is also one of the enablers for one of the cornerstones in quality management; the ability of an organization to continuously improve itself (Bergman & Klefsjö, 2010).

According to Robbins & Judge (2010, p. 281) a learning organization can be defined in this way: *"A learning organization is an organization that has developed the continuous capacity to adapt to change"*, while Garvin (Garvin, 1993, p. 80) provides us with a slightly different definition to this phenomenon: *"A learning organization is an organization skilled at creating, acquiring and transferring, and at modifying its behavior to reflect new knowledge and insights."*.

While the main point is similar and contains the same reasoning about the ability of an organization to adapt to change, Garvin's definition goes into more detail specifying several components needed for it to take place, namely the ability to create, acquire, to transfer and to act on new knowledge. What should be noted when it comes to the definitions of a learning organization is that both the definitions mentioned earlier contain prerequisites needed for the definition to be fulfilled, meaning that not all organizations can be viewed as "learning organizations" according to the definitions.

The way in which an organization learns and develops can be categorized into different types depending on the nature of the learning that takes place within the organization (Bergman & Klefsjö, 2010). One framework for organizational learning is illustrated in Figure 4, which describes three main types of organizational learning. When the learning takes place within the current frames of the organization and the organization itself and its values are not questioned or altered, the organization is engaged in single-loop learning (Bergman & Klefsjö, 2010).

An organization is engaged in double-loop learning when the organization challenges and modifies the underlying assumptions of the system and its goals. In essence meaning that the organization has the ability to alter the knowledge and rules that drives the current behavior in order to perform better. For example, when an error is detected the learning organization adapts to this by modifying its organizational framework including its policies, objectives and standards. Double-loop learning is difficult to achieve, since it challenges basic assumptions and fundamental values that the organization is built upon (Bergman & Klefsjö, 2010).

A higher level of learning has also been suggested, namely the triple-loop, which occurs when an organization adopts and changes the way it learns based on previous experience and based on this experience develops new avenues for learning (Romme & van Witteloostuijn, 1999). However, Tosey, Viser & Saunders (2011) points out that there is a limited consensus about how triple-loop learning should be defined other than that is should be considered as a higher level of learning than double-loop learning.

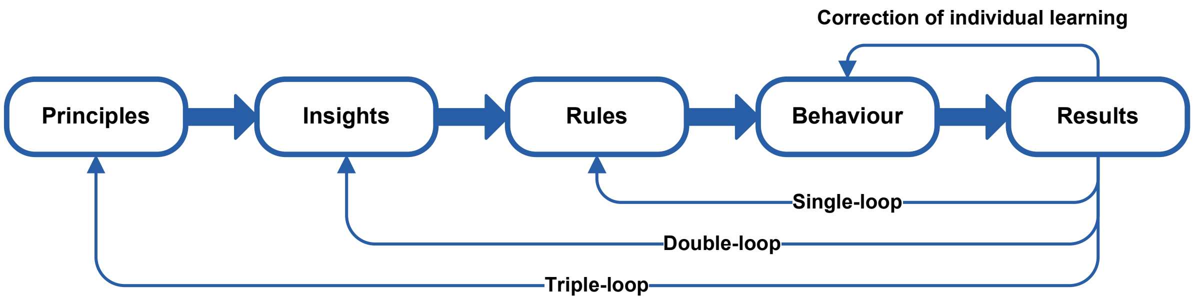

Figure 4. Illustrating different types of organizational learning, adapted from (Bergman & Klefsjö, 2010, p. 413)

An organization's ability to learn from development projects and thereby learn from experience is essential for its ability to achieve substantial improvement in its product development performance over long stretches of time (Wheelwright & Clark, 1992). As for what constitutes for important events to learn from Wheelwright & Clark (1992, p. 287) state that in projects *"Episodes when things go wrong (or, sometimes, right) are the raw material for learning"*. However, according to Wheelwright & Clark (1992) learning is not something that occurs naturally nor is it normally the natural outcome of a project even when the project itself is successful, due to two fundamental problems that inhibits the learning and the sharing of experience.

Firstly they argue *"[…] that the performance that matters is often a result of complex interactions within the overall development system"* which means that it is difficult to learn from the sources with the greatest potential for learning (Wheelwright & Clark, 1992, p. 284). The second issue is related to the goals and incentives of the organization. Here Wheelwright & Clark (1992) point out that organizations and their systems of incentives tend to favor moving ahead to a new project instead of taking the time needed to learn from a previous project. Therefore they argue that it is unlikely that the participants in the projects by themselves will devote time to problems that belongs to an old project. For that reason they argue that the organization has to provide the effort and attention needed in order to learn from a newly completed project (Wheelwright & Clark, 1992). They also argue that finding the actual issues in the product development process is unlikely to happen without careful and systematic effort from the organization, since the product development process in itself is inherently complex (Wheelwright & Clark, 1992).

3.4 Processes

Oxford Reference Online provides us with the following definition of a business process: *"A specific, structured, and managed set of work activities, with known inputs, designed to produce a specified output, e.g. product development, order management, and performance monitoring"* (Oxford University Press, 2009). Another description of a process is: "*a network of interrelated activities that are repeated in time, whose objective is to create value to external or internal customers*" (Bergman & Klefsjö, 2010, p. 42). As mentioned in the cornerstone model one key area in quality management is the need for a focus on processes and one reason for this being: "*The core idea behind this principle of TQM is that organizations are sets of interlinked processes, and that improvement of these processes is the foundation of performance improvement"* (Samson & Terziovski, 1999, p. 397).

A business process can be divided into three types depending on their role within the organization; main processes, support processes and management processes (Bergman & Klefsjö, 2010). The aim of the main processes is to fulfill the needs of external customers or to improve the products produced by the company. Supporting processes consist of the business processes concerned with providing support and resources to the main processes and finally the management processes are made up of the processes that make decisions for the organization.

Slack, Chambers & Johnston (2007) describe four important characteristics that can be used to define the behavior of a process and these are the **volume dimension**, the **variety dimension**, the **variation dimension** and the **visibility dimension**. The volume dimension is related to the volume of the output from the process. High volume processes generally have a more standardized and repeatable work task and are more suited for specialized equipment than a low volume one. On the opposing side of this dimension are processes where the volume demand from the customer is low. The variety dimension describes how adaptable to varying requirements the process must be in order to satisfy the customers. With high variety the complexity of the task and the flexibility have to be higher than in a low variety process. The implications of a process with low demand for variety are that it is easier to define the process and to standardize it. High variety allows for a high degree of specialization towards the needs of the customer. The variation dimension is concerned with how demand varies over time. If the variation is high the process will have a greater need for the ability to change and anticipate demand as well as being flexible in order to have the capability to react to changes. A process characterized by low variation in demand will instead remain more stable and will be easier to standardize (Slack, Chambers, & Johnston, 2007). The visibility dimension describes to what extent the customer experiences the process and the degree of the process that is made visible to its customers (Slack, Chambers, & Johnston, 2007).

All processes are subjected to the phenomenon of variation, which is a fundamental part of all systems (Magnusson, Kroslid, & Bergman, 2009). This variation is due to both internal factors in the process as well as the input factors of the process, such as supplier quality. The consequences of variation are that the performance of the output from the system will deviate from its intended targets leading to costs through unpredictable outcomes and loss of quality (Magnusson, Kroslid, & Bergman, 2009). There are two basic types of variation (Magnusson, Kroslid, & Bergman, 2009):

- Common cause variation: The variation naturally inherent to the system that cannot be influenced without modifying the system.
- Special cause variation of variation: Variation from specific causes leading to unexpected changes in the system output.

In order to reach great improvements in a system, both types of variation often need to be addressed, by minimizing the variation and also by making the system less sensitive to it (Magnusson, Kroslid, & Bergman, 2009). Achieving less sensitivity to disturbing variation, or noise, can be done through applying robust design methodology.

Another way by which a process can be improved is waste analysis (Magnusson, Kroslid, & Bergman, 2009), in which wastes are identified and reduced or removed. In lean methodology seven wastes have traditionally been discussed: Overproduction, waiting, transport, inappropriate processing, unnecessary inventory, unnecessary motion and defects (Bergman & Klefsjö, 2010). However, in more recent years this list has been supplemented with one further waste that is highly relevant to this thesis, namely Latent skill (Bergman & Klefsjö, 2010). This waste means that not all skills of an organization are utilized, such as knowledge and creativity (Bergman & Klefsjö, 2010).

3.5 Performance measurements

Slack, Chambers & Johnston (2007, p. 582) define performance measurement as "*the process of quantifying action*" and state that performance measurement is a prerequisite for judging the quality of a process. Additionally, according to Franceschini, Galetto & Maisano (2007, p. 5), "*identifying and controlling process performance and evolution are indispensable actions taken to decide which strategies to carry out*", and a measurement system is needed to test if a process meets the needs of the stakeholders, i.e. test the quality.

According to Melnyk (2004), there are three basic functions provided by performance measures: Control, communication and improvement. Control, since measurements enable evaluation and control of the performance of resources; communication since performance can be communicated both to internal workers and external stakeholders; and improvement since the measurements point to gaps between actual and ideal performance of a process. Measurements do, however, not tell everything, such as cause and effect without additional data (Franceschini, Galetto, & Maisano, 2007). A performance measurement target not being met does not tell why it has not been met, but rather signals to investigate the situation further (Franceschini, Galetto, & Maisano, 2007). Measurements can also have an impact on organizational behavior and inertia, meaning that the organization becomes used to striving towards scoring high in certain measurements, resulting in difficulties if you later want to achieve changes in how the organization works (Franceschini, Galetto, & Maisano, 2007). Another potential risk of implementing measurement initiatives is that they can be viewed as control devices solely for management, resulting in distrust, and employees might also try to circumvent desired outcomes (Parmenter, 2007). There is also a risk related to measurements in that for example managers might act upon an individual reading that might be the result of normal variation, which Scherkenbach & Deming (2001) argue can lead to increased variability in the outcomes. This is also one of the reasons why it is useful to present changes in a measurement over time in a control chart (Motschman & Moore, 1999). The control chart can then be used to show if the process is under statistical control or if the measurement is out of the estimated control limits which in that case would warrant further investigation and indicate that the process is no longer under control (Motschman & Moore, 1999; Magnusson, Kroslid, & Bergman, 2009).

One challenge of devising a system for performance measurement is achieving balance between having a few key measurements that provide a holistic view, and having several more detailed measurements that point out more nuances (Slack, Chambers, & Johnston, 2007). Tangen (2003) argues that there is a need to use several performance measures, since all measures have advantages and disadvantages, and using just one also often results in sub-optimization. However, Franceschini, Galetto & Maisano (2007) warn of using too many measurements, since they then risk being ignored. Slack, Chambers & Johnston (2007) propose that a compromise between having several detailed and a few key measurements can be reached by ensuring that the measures are clearly linked with the strategy.

3.5.1 Indicators

According to Oxford University Press (Law, n.d.) one definition of an indicator is "*A measurable variable that gives information regarding performance or prospects*". Performance measures can be divided into different types, for example Parmenter (2007) divides them into *Key Result Indicators (KRI), Performance Indicators (PI) and Key Performance Indicators (KPI).* Key Result Indicators are such that tell how you have been doing in a perspective, and show you in what direction you are going. They do not however point to what has to be done to alter the direction. Examples of such indicators are customer satisfaction, profit or return on capital. Performance Indicators lie beneath KRIs, and according to Parmenter (2007) these tell you what to do in order to enhance performance. They could for example be profitability of top 10 percent of customers or profit of specific product lines. Like Performance Indicators, Key Performance Indicators tell you what to do in order to increase performance, except by acting on these you will enhance performance drastically, since they focus on the most critical aspects of the process. Examples of Key Performance Indicators are timely arrivals and timely departures for an airline. Franceschini, Galetto & Maisano (2007) speak of initial indicators, intermediate indicators and final indicators, where they represent the quality of materials or services from suppliers, quality of internal processes, and result indicators such as customer satisfaction or production cost. They also distinguish *basic indicators* from *derived indicators*, where basic indicators are the building blocks which can be aggregated to sets of indicators or derived indicators. Derived indicators are in turn syntheses of two or more basic indicators (Franceschini, Galetto, & Maisano, 2007). According to Walsh (1996), the focus on improvement should be on drivers and not outcomes, which is done through identifying what activities influence the desired outcomes and measuring these. However, Parmenter (2007) suggests that many companies tend to use result indicators more often than KPIs, which only enables them to see the results from past actions rather than have something to base decisions on today. Muckler & Seven (1992) argue that all measurement systems in science and technology contain subjective elements such as in how they are selected, collected or analyzed, and according to Walsh (2005), the more subjective a measure is the less-than-perfect it is.

Franceschini, Galetto & Maisano (2007) present properties for representing a process by having a set of indicators. They state that the set should be *exhaustive*, meaning that no process state contradicts the represented process and indicator, as is the case if different process states result in the same manifestation. This can be the result of poorly constructed indicators or if not all dimensions of the process are considered. The set should also be free from redundant indicators, meaning an indicator that has no impact on the exhaustiveness of the set. If using derived indicators, they should be monotonous, meaning that changing the state of a sub-indicator should result in a different derived indicator.

Franceschini, Galetto & Maisano (2007) also present a methodology for constructing and checking a set of indicators which is based on top-down testing: Firstly, the process needs to be identified as well as its representation targets which should be consistent with the strategies (accessory properties). Then indicators should be constructed and made sure to be consistent with representation-targets, be exhaustive and non-redundant. Then the general properties should be tested, i.e. level of detail, non-counter-productivity, economic impact and simplicity of use. Lastly the properties of the derived indicators should be tested. The entirety of this methodology for constructing indicators can be found in appendix C.

A number of methods have been constructed to use when evaluating performance indicators. The U.S. Department of the Treasury developed a test in 1994 following three general verification criteria concerning the data, indicators and the measurement system, presented in Table 2 (Tuck & Zalesky, 1994).

Table 2. The Treasury Department Criteria test, based on (Tuck & Zalesky, 1994)

Data criteria	
Availability	Can the data be collected?
Accuracy	Are the data reliable?
Timeliness	Are the data collected and reported frequently enough?
Security	Are there privacy or confidentiality concerns?
Costs of data collection	Are there sufficient resources for data collection and is it cost effective?
Indicator criteria	
Validity	Are changes in the value clearly desirable?
Uniqueness	Are there redundancies?
Evaluation	Can the indicators be interpreted?
Measurement system criteria	
Balance	Is the mix appropriate or is there bias?
Completeness	Are all major components covered?
Usefulness	Can and will the results be used?

The three criteria test is another indicator test presented by Performance-Based Management Special Interest Group in 2001, which subjects the indicators to three broad criteria, shown in Table 3 (Franceschini, Galetto, & Maisano, 2007):

Table 3. The ”Three Criteria” test, adapted from (Franceschini, Galetto, & Maisano, 2007)

Strategic criteria	Do measures align behavior with strategy and enable strategic planning?
Quantitative criteria	Do measures point to the gaps between performance targets and the current state?
Qualitative criteria	Does the organization perceive the measures as valuable?

3.6 Framework for failure reporting

How to create a process for failure reporting and management is related to the field of reliability engineering as the aim of this field is to find the causes and the consequences of failures, and working on reducing, eliminating and preventing the effects of said failures (Bergman & Klefsjö, 2010).

Motschman and Moore (1999, p. 164) defines a corrective action as: *"[…] the action taken to eliminate the causes of an existing nonconformity, defect, or other undesirable situation in order to prevent recurrence"*. Corrective actions should be contrasted with preventive actions whose aim instead is *"[…] actions taken to eliminate the causes of a potential nonconformity, defect, or other undesirable situation in order to prevent recurrence"* (Motschman & Moore, 1999, p. 164).

While one could argue that it is better to do things right the first time, this is not always possible, since the number of potential failure modes can by high and the knowledge of the system might not be complete. Software, for example, is known for having these issues (Sommerville, 2007) and just preventing all faults from occurring from the beginning might therefore be impossible due to high complexity of the system and due to both limited resources and time available in development projects. This is also supported by Krouver (2002) who argues that in complex systems, the number of failure modes can be large and that ways for mitigating this are therefore not fully known. Moreover striving towards a culture that attempts to always favor to do thing right the first time can be harmful since this can result in design teams who favors less risky solutions even while the alternatives could be more beneficial in the long run, which aside from reducing the customer value generated form product development, also can reduce the organizations innovativeness (Thomke & Reinertsen, 2012). Because of this, methods for designing in quality have to be complemented with methods for testing in quality.

Stockhoff (2010) argues that an organization needs to define a formal process for failure reporting and corrective actions in order to drive improvements in the areas of reliability, availability, maintainability and to improve the safety of the design. One framework used to deal with these kinds of issues is known as FRACAS which stands for "Failure reporting and corrective action system" (Stockhoff, 2010), but is also according to Hallquist & Schick (2004, p. 663) commonly referred to as a: "*closed-loop analysis and correction action process*".

The oldest source mentioning FRACAS found during the literature review was MIL-STD-2155 (Department of defense USA, 1985, p. 9). This document mentions that "*The primary objective of a closed-loop FRACAS is to document failures and faults and to disseminate the data"*, and while other authors mention a similar purpose (Hallquist & Schick, 2004) and (Ling, Hsieh, & Cowing, 2004), Lee, Chan and Jang (2010, p. 1) give a broader definition of the main objective of FRACAS: "*Its objective is to provide engineering data for corrective actions, assess historical reliability performance …, develop patterns for the deficiencies, and to provide data for statistical analysis"*.

In this thesis FRACAS is defined as a process whose main goal is to act as a closed-loop failure reporting system, where a closed-loop failure system according to Department of defense USA (1985) is defined as a closed system in which all faults and failures are recorded, analyzed and corrected in order to prevent them from reoccurring. Lee, Chan and Jang (2010) describe two approaches to FRACAS: A process oriented approach and a data centered approach. Instead of the data centered approach where focuses lies on constructing a structured database with the aim to handle the FRACAS they argue for process oriented approach were a business process model describes how the process should be conducted. In Table 4 an example of the major steps in a FRACAS process can be seen. This model can be compared to two other frameworks that were found and can be seen in Appendix B.

Table 4. An overview of the steps in the FRACAS framework adapted from (Lee, Chan, & Jang, 2010, p. 7)

Step:	Task:	Information generated from task:
1.	Observe a failure of an item or a product	-Item observation data -Time/location/environment
2.	Document failure symptom and relevant information	-Failure description -Expected root cause
3.	Verify failure	-Check list
4.	Isolate the lowest leveled suspect item	-Failure mode
5.	Retest after replacement of suspect item	-Test report
6.	Verify the failure of isolated item	-Repair description -Verification report
7.	Failure analysis	-Analysis method -Analysis report
8.	Search for similar failure history	-Database search results
9.	Establish the root cause	-Failure mechanism
10.	Determine corrective action based on the analysis result	-Analysis result
11.	Incorporate corrective action based on the analysis result	-Action specifications
12.	Verify that the new corrective action has no adverse effect	-Performance report
13.	Verify effectiveness of the proposed action	-Effectiveness result
14.	Incorporate corrective action into all products	-Action specifications

Hallquist & Schick (2004) discuss in their paper three common issues that organizations face after implementing FRACAS. The first issue that they mention is the complex interactions between different groups within the organization as well as with external actors that often occur in the FRACAS process. The reasons for this are that due to the aim of FRACAS the process usually has to involve actors from several functional groups. Data both have to be delivered from and to a wide range of actors including manufacturing, operations, testing, failure review board, suppliers, etc. They also mention that the complexity of the process might grow over time as more stakeholders wish to be included in the process. The main consequences of the first issue according to Hallquist and Schick (2004) is that the number of steps in the process might increase and that it becomes difficult to close issues and that the cycle time for the process becomes unnecessarily long.

Another common issue is the lack of prioritized goals due to different perceptions of the aim of the FRACAS process. This problem can arise when the goals and expectations for the FRACAS process from the various actors involved has not been discussed and prioritized.

The final issue described by Hallquist & Schick (2004) is the use of ineffective and inefficient data tracking. This is an important issue since one of the key objectives of the FRACAS is to gather and report meaningful data, and there can be several causes to this issue. They can be related to the design of the reporting system that affects how the user behaves. If for example the time to record the data takes too long and is too cumbersome this can result in skipped fields in the report or at worst that the issue is not reported at all. Hallquist & Schick (2004) also argue that the use of free flowing text windows can confuse the issuer and result into wrong data, or no data being entered into the field. While missing or gathering the wrong data is an issue, gathering too much data can also be problematic and even harmful if the amount of data increases the difficulty to analyze, scan and to identify trends in the data (Hallquist & Schick, 2004).

To come to terms with these three issues Hallquist & Schick (2004) argue that the goals for all users of the system and interested parties have to be defined and understood. They also mention that training in the process is important, since it will give the users a better chance of understanding what is expected of them and increase the acceptance of the system. Introductory courses can also according to Rubenowitz (2004) be beneficial for several reasons including creation of routines and guarantees that suitable instructions are provided from the start and reduce the risk for conflicts, since they teach about what is expected. Maginez, Brombacher & Schouten (2009) also suggest that has to be efficient communication channels between the issuers of the information and the users of the information aside from a database since the information found in these databases often suffers from lack of accuracy or lack of meaningful information. Hallquist & Schick (2004, p. 666) also provide a few questions that can be used as a starting point for modifying the FRACAS:

- *"Does the workflow process previously defined work in this environment?"*
- *"Can the data be efficiently entered into the system?"*
- *"Can the expected outputs be generated?"*
- *"Is the system easy to use and to understand?"*

3.6.1 Root cause analysis

For a FRACAS process to be effective it has to ensure that the right corrective actions are taken, and here the process relies on its ability to identify the causes of the failures that it tries to mitigate. Therefore the FRACAS process and its ability to take corrective action lies in its ability to identify the root cause of the failure. Monroe (2010, p. 389) puts it this way: "*Without root cause analysis, effective corrective action is impossible.*

Without corrective action, root cause is a waste of time". One common sign indicating that this is not the case and that the corrective actions have not been fully successful is according to Okes (2008) and Bhaumik (2010) that the same problem occurs again. Okes (2008) further argues that this indicates that the root cause analysis could lack adequate depth and therefore have been conducted on the wrong level.

The root cause analysis (RCA) aims at uncovering the underlying reasons or causes for a fault in for example a product or process so that corrective action can be taken in order to correct the fault and to prevent its reoccurrence (Monroe, 2010). Where a root cause according to Finlow-Bates (1998, p. 12) can be defined as *"the step in the tangible cause-effect chain where the owner of the final undesired effect can make an economically justified intervention to produce a long-term removal of the undesired effect"*.

Okes (2008) argues that there are two levels of causes to a fault. First and most evident are the physical causes. A physical cause could for example be identified as a failed component where the fault is considered resolved after merely having replaced the component. The second level according to Okes (2008) is the system causes and they represent the underlying reasons for the occurrence of the physical cause. Okes (2008) further argues that it is normal for organizations to stop at the physical causes without digging deeper in order to uncover the system causes and by doing so miss out on the opportunity to prevent reoccurrence.

Vanden Heuvel et al. (2008) go a bit further and present a richer picture on the different levels that a root cause analysis can be made; these different levels are presented in Figure 5. Vanden Heuvel et al. (2008) illustrate that by moving deeper into the levels, the commonality between some failures increases and therefore a correction to a failure on a deeper level can impact other failures as well. While moving into a deeper level also increases the level of learning due to a better understanding of the mechanisms behind the failure there is also a tradeoff between this benefit and the effort, cost and skill needed in order to conduct the RCA and to undertake the needed corrective actions. By moving deeper into the underlying causes of the system behavior Finlow-Bates (1998) argues that something reminiscent of double-loop learning can be achieved. In the picture the different tops in the pyramid represent different causes and below them their different emergent causes can be seen. The picture also illustrates how the causes intertwine with each other and become shared when the level becomes deep enough.

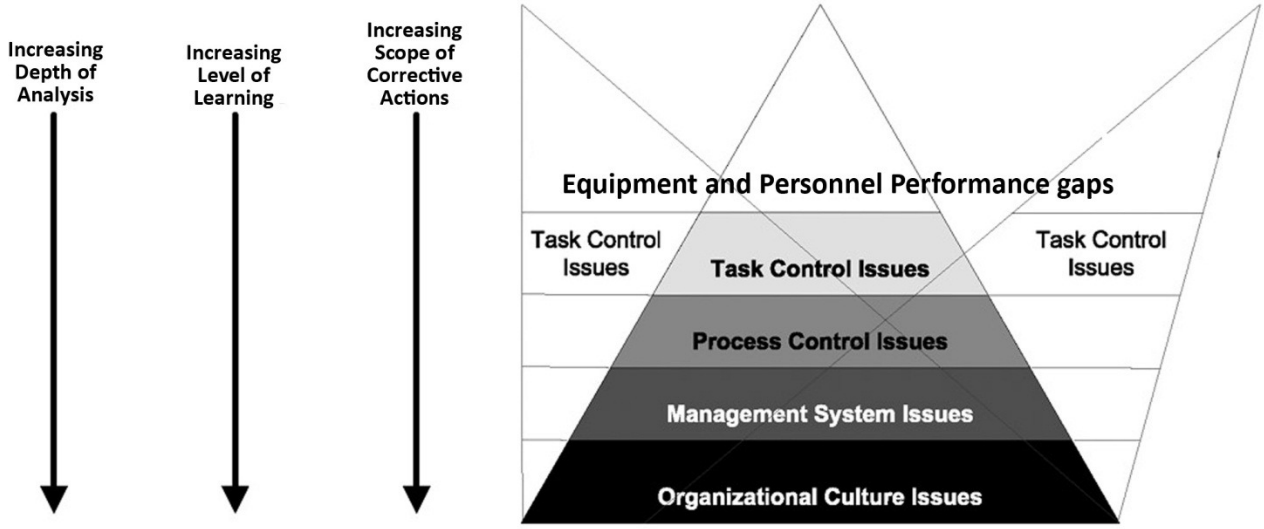

Figure 5. The possible depths of an RCA, adapted from Root Cause Analysis Handbook figure 1.2

An RCA consists of three main components; the problem definition, the possible causes and the supporting data (Okes, 2008). According to Monroe (2010) an RCA should when completed provide the following four things:

- The root cause of the problem.
- Identification of contributing factors and weaknesses.
- Provide a better understating of the process surrounding the issue.
- Provide information that can be used for the corrective action plan.

The RCA itself consists of an investigation that tries to explain why a certain event unfolded and/or occurred (Monroe, 2010). Okes (2008) argues that there are different types of problems: analytical and creative problems and single event and repetitive problems. Before the investigation is initiated and once an issue that requires corrective action has been observed the nature of the problem must be clearly defined. According to Monroe (2010) the problem statement should have the following characteristics: Measureable, observable, manageable and specific. The first step needed in order to identify the cause is to analyze the symptoms in order to understand the current situation. Following this, theories should be formulated that try to explain the likely causes of the failure (Monroe, 2010). The final step in identifying the root cause is to test these theories and to constantly question them by asking "why" until a suitable level of analysis has been reached. Monroe (2010, p. 398) suggests two questions that can be used in order to decide whether the root cause has been found or not:

- *"Does the data suggest any other possible causes?"*
- *"Is the proposed root cause controllable in some way?"* This question can be used to test if the level of the root cause is meaningful. Moving beyond a controllable level provides no further value.

According to Finlow-Bates (1998) it is important to be aware of a common misconception regarding the root cause which is that the term root cause itself implies that there is a single real root cause that must be found. This is according to him not true since there often can be several potential root causes. Moreover he argues that the view on what constitutes as a root cause depends on the owner of the problem.

Part IV: Empirical Study

"In God we trust; all others must bring data"
W. Edwards Deming

In this chapter the results from the empirical study are presented. This chapter is built upon several sources, including the writers' own experiences as PROTUS coordinators and from interviews with engineers and managers related to the process.

4 Empirical study

The data in this chapter were collected through observations of workflows, internal documents, processes and interviews with Volvo employees. Information for which no source is stated comes from observations. This chapter begins with a general introduction to Volvo GTT Powertrain Engineering and some background and description about the system named PROTUS used to support the process for failure reporting and handling at Volvo.

Following this the subsequent subsections describe the system in more detail recounting the findings from the interviews for each major process step. Then the observations and the interviewees' perceptions of the PROTUS process, its management, supporting systems and documentation are presented.

4.1 Volvo GTT Powertrain Engineering

AB Volvo is a Swedish manufacturer of trucks, buses, construction equipment and drive systems for industrial and marine applications, which employs about 100 000 people throughout the world and has production facilities in 20 countries (Volvo Group, 2012). The product range includes the brands Volvo, Renault Trucks, UD Trucks, Mack, Eicher, Volvo Penta, SDLG, Prevost and Nova Bus (Volvo Group, 2012).

Group Trucks Technology (GTT) is a business unit within AB Volvo that develops trucks for the group, and Powertrain Engineering (PE) is one of its subdivisions, which is responsible for the development of heavy engines, gearboxes and axles. The headquarters are located in Göteborg, Sweden, where most of their heavy duty engines are developed, but they also have product development in Malmö, Sweden; Lyon, France; Hagerstown, USA; Ageo, Japan and Curitiba, Brazil, with a total of approximately 1700 employees. PE's products are manufactured by Group Trucks Operations (GTO), where the products that are developed by the Göteborg unit are manufactured in Skövde and Köping in Sweden. Figure 6 presents the PE organization at the Göteborg unit, which also includes Malmö.

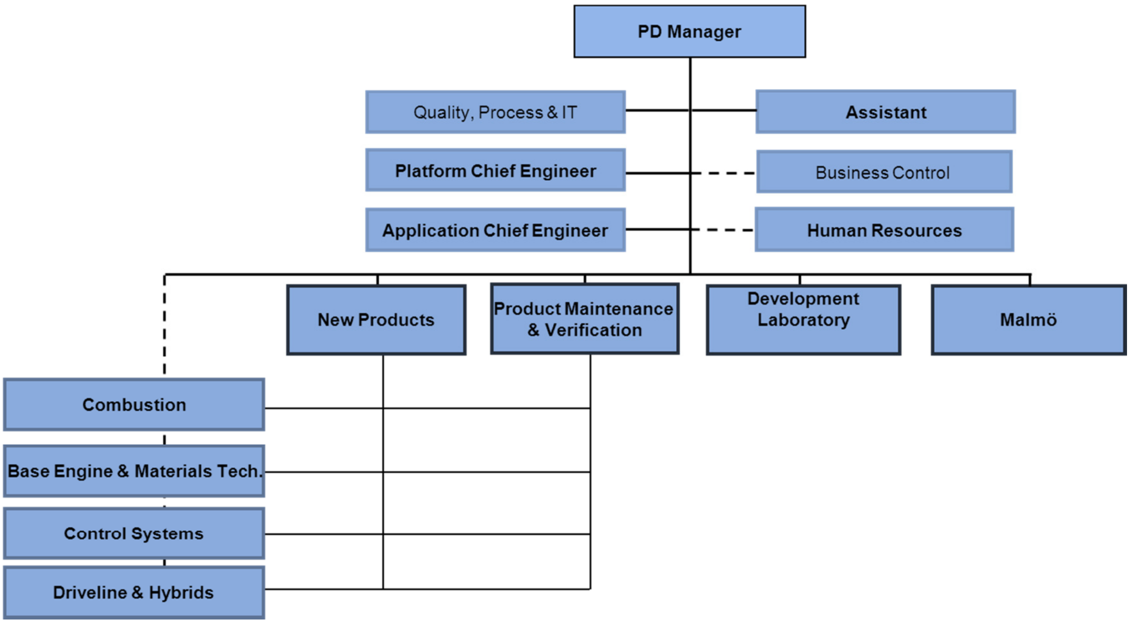

Figure 6. Volvo Group Trucks Technology Powertrain Engineering Göteborg organization (Internal document, AB Volvo)

The PE development organization is divided into four different sub system developers – Combustion, Base Engine & Materials Tech., Drivelines & Hybrids and Control Systems – which are spread geographically. The different sites also have units that are responsible for maintenance, verification, quality and process development. At the Göteborg unit, all subsystems and functions are located in separate places from one another, either by being located on different stories or in different buildings.

4.1.1 Product development within PE

PE develops products in projects, where each project is led by a Chief Project Manager (CPM) who has the overall responsibility whereas the engineering is led by the Project Manager Engineering (PME). The project allocates working hours from engineers in the subsystems, who while being in their line organization can work on several projects simultaneously. The subsystems are divided into design groups and further into function groups, which are responsible for particular systems and components.

Volvo projects follow a stage gate process called GDP (Global Development Process) in which certain criteria must be met in order to pass a gate. One of these criteria is the amount of failure reports, where a certain target must not be exceeded at the time of the gate review. The quality of a project is the responsibility of the Project Manager Quality (PMQ), who conducts FMEA at the start of a project, and partakes in PROTUS meetings. Each subsystem has an assigned project leader (PL) who is responsible for the subsystem’s deliveries to the project. There are also Work Package Leaders (WPL) who are responsible for systems within a subsystem. Component testing and planning thereof is done by a PL for verification. Products developed in Göteborg are tested in powertrain test cells in a different building but at the same site as where the design engineers are seated. The products are also field tested in vehicles throughout Europe and at Volvo's proving grounds. The test runs in test cells and at the proving grounds follow standardized regiments of duration and shape, where the type of cycle chosen depends on whether a longevity test or a feature test is conducted.

4.1.2 Introduction to PROTUS

The PROTUS system at Volvo has its origin as a system for handling BOM (Bill Of Materials) for prototypes built during product development. From the beginning the system existed as a mainframe system, but has since then evolved into its current form; as a web based system. Today the system is used worldwide within the entire Volvo organization, during both the concept generation phase and prototype testing phase within Volvo's GDP for product development.

Since its development the system has also grown in both the scope of tasks that are covered as well as in the amount of features and functionality that the system provides. According to Volvo (2012) "*PROTUS is a vital tool that allows us to specify a test prototype, support the building of the prototype and to report assembly problems or deviations, support the testing of the prototype and to report problems linked with the production process*". Therefore PROTUS can be seen as a data management system that handles three related tasks; specification of test prototype, support for building the prototype and as a fault reporting and follow-up system for issues related to the product development and the initial production process.

The objective relevant to this thesis is the part of PROTUS concerned with handling problem reporting and follow-up of tasks. The objective with this process is according to Volvo to ensure a systematic and uniform handling of failures that arises in connection with product development and to ensure that these faults are corrected. The data stored in PROTUS are also used for calculating reliability of products and components in projects using RGM (Reliability Growth Method).

4.2 Failure reporting at Volvo GTT PE

Problems that occur during development and pre-production are handled through reports created in PROTUS and these are commonly referred to as a PROTUS report or solely PROTUS. The PROTUS reporting system also handles reports related to cost and quality improvement projects called PCR reports (Product Change Request) which are stored in the same database as the failure reports. They are however handled in a different process and not related to the area of failure reporting and corrective actions and therefore will not be discussed further.

The idea with the PROTUS system for problem reporting is that anyone should be able to report a problem and to enter a report into the PROTUS database in order to ensure that no faults are missed. The only prerequisite is to have access to the PROTUS system. The system is only available to actors within Volvo, and external actors such as suppliers do not have access to PROTUS. The person who finds the fault is denoted as the originator in the PROTUS process and the originator can therefore be seen as the one who initiates the process. A general outline of the main phases of the process from report creation until report closure is illustrated in the SIPOC, Figure 7. This SIPOC is based on our own view and experiences of the process.

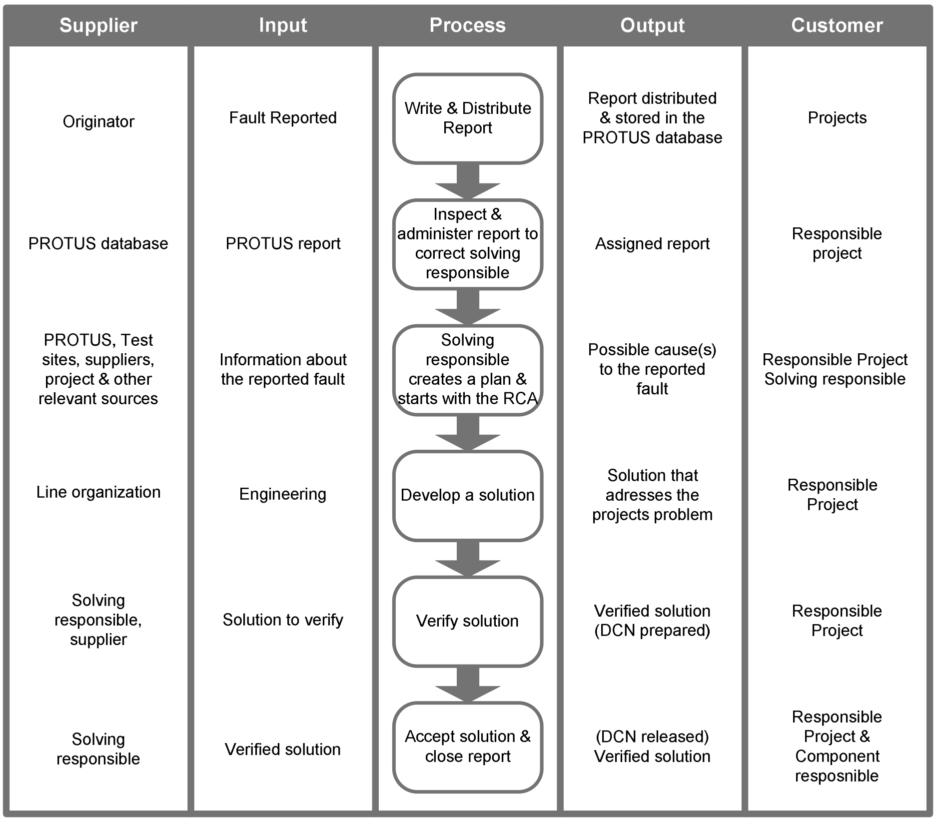

Figure 7. SIPOC model outlining the main steps in the current PROTUS process

There are four main roles in the PROTUS process for failure reporting:

- **Originator**: The originator is the person who identified the problem.
- **Issuer**: The user who writes and issues the report into the PROTUS system and depending on the circumstances the same individual can be both issuer and originator.
- **Handler** or **Coordinator**: The individual responsible for monitoring the reports belonging to a specific project. Both these names are used interchangeably.
- **Solving Responsible (SR)**: The engineer responsible for resolving the problem, commonly the SR for a report is the component responsible for the part related to the fault.

When the problem has been observed, the issuer writes and distributes a report containing information about the problem. This report is stored in the PROTUS database and acts as a living document, updated as the case is processed and progresses through the PROTUS process.

The handler will at some point, either through using filters to search for reports related to the handler's project or from being alerted by an E-mail, notice the new report. At this point the handler inspects the report, ensuring that the information in it appears to be correctly filled in before the handler identifies the engineer who is considered to be the SR for this report and appoints them as responsible for the report, by setting the identified engineer as “Solving Responsible” for the report in the PROTUS system.

The designated SR is automatically notified by an E-mail stating that they have been set as SR for a report. The responsibilities of the SR in the PROTUS process is then to lead the work with the report and ensure that the fault is corrected, including the actions required to identify the cause of the problem, determine and develop needed corrective actions and to verify that these actions resolve the problem.

When the verification has been completed the project owning the report has to accept the solution in order for the report to be closed. This is done at a meeting, usually during a PROTUS Team Meeting (PTM) in which the PMQ and PME related to the responsible project participate and jointly accept the solution. When the solution and its verification have been accepted by the project the problem is considered resolved.

When the nature of the problem makes it necessary to modify one or several parts in the product a Design Change Notice (DCN) has to be created and approved. The DCN contains information about a design change for an early or late change to the design of a part (determined by part version) and is documented in KOLA (**Ko**ntruktionsdata **La**stvagnar, Swedish for Design Data Trucks). The DCN has to be approved and released before the report can be closed

The main customer to a PROTUS report is the project who owns the problem and they can also sometimes be a direct supplier to the system when they themselves issues PROTUS reports. The system is governed by a super user located at each site providing local support and user management and changes to the system itself are decided by a committee located in France.

Aside from creating and viewing reports, the PROTUS system also allows the users to view and modify reports, search for reports using different filters and search criteria and to create statistical summaries for the reports. Throughout the PROTUS process different status levels are used in order to keep track on reports; these status levels correspond to a certain process step, indicating that a certain action has been carried out, or has to be taken. They are mainly used for report monitoring and statistics. A complete reference for all status levels can be found in Figure 18 located in Appendix C. The more commonly used status levels are also shown in the process maps Figure 8 and in Appendix D together with the activity that they are related to.

A PROTUS coordinator is the person employed by a project who is responsible for overseeing all PROTUS reports within that project. The coordinator is set as handler of the majority of reports, but there can also be other handlers, as is the case in one ongoing project where group managers are assigned as handlers for reports with low fault point numbers. Aside from identifying the correct SR for a report the handler fulfills a number of different purposes as well. One coordinator described the role as *“oil that smears the cogs and ensures that the process runs smoothly”*. The handler monitors the reports and sees to that they are filled in correctly and updated with the latest progresses or concerns regarding the issue. The project PROTUS coordinator position also includes summoning and chairing PTMs as well as reporting to the project management about the PROTUS situation.

The procedure for identifying the correct SR is for the most time straightforward and is mainly dependent on experience and available lists of engineers responsible for the parts. However for the subsystem Control Systems it can at times be difficult for the coordinator to identify the correct SR since most software related reports are written on a control unit (hardware unit on which the software is installed), on which several software modules are installed. The control unit represents a single part number, but there are often several engineers developing the different software modules for each control unit, and therefore it is not possible for the coordinator to identify the correct SR based on the part number.

Moreover for faults written on software it is not always certain that the software is causing the problem, but instead it is possible that the issue can be related to a physical component or in another software or part not belonging to GTT PE such as the in-cabin truck display which is the responsibility of GTT Vehicle Engineering. Vice versa a report written on a physical part can sometimes be related to software. To complicate matters further it is not always suitable or possible to make the necessary changes in the part reported as faulty due to either economic reasons or due to physical limitations in the parts. Therefore it is not always certain that the identified SR is the most suited as SR since this engineer cannot find the root cause or develop a solution.

The majority of the status changes are made by the handler since the SR usually only has authority to change the report status to 3 (investigation and work on solution) and thereby indicating that they have accepted the report and for other changes in status levels they are supposed to contact the handler. As one of the SR interviewees pointed out, they cannot view all status levels that can be set since they can only see those that they have authority to choose.

There were varied reactions when the SRs were asked what they thought about PROTUS and its purpose. One SR said:

> *”PROTUS is good, but time consuming. Not a bad way of following up issues”*

While another called it a ”*Necessary evil*” and another questioned its value in larger projects ”*In large projects you could question if a PROTUS system is needed in the first place*”. A common response was also that they found the system easy to use and that worked well. The SRs appeared to view PROTUS in different ways, as some saw it just as a reporting system for the projects, while others viewed it as a way to be informed about problems, being a natural part of their development work that provides them with feedback on their components. It became clear that several SRs thought of PROTUS as just a system when first asked about and did not think about the entire failure reporting process.

Based on both our experience as coordinators and trough information collected during the interviews a more detailed process map was constructed than the SIPOC which can be seen in Figure 7, illustrating the entire PROTUS process including the problem flow and the work of the coordinators, in which the activities have been arranged according to the area of responsibility that they belong to. This process map is illustrated in Figure 8 and gives an overview of the more detailed process description provided in subchapter 4.3 and 4.4. A second process map was also developed and can be found in Figure 19 located in Appendix D.

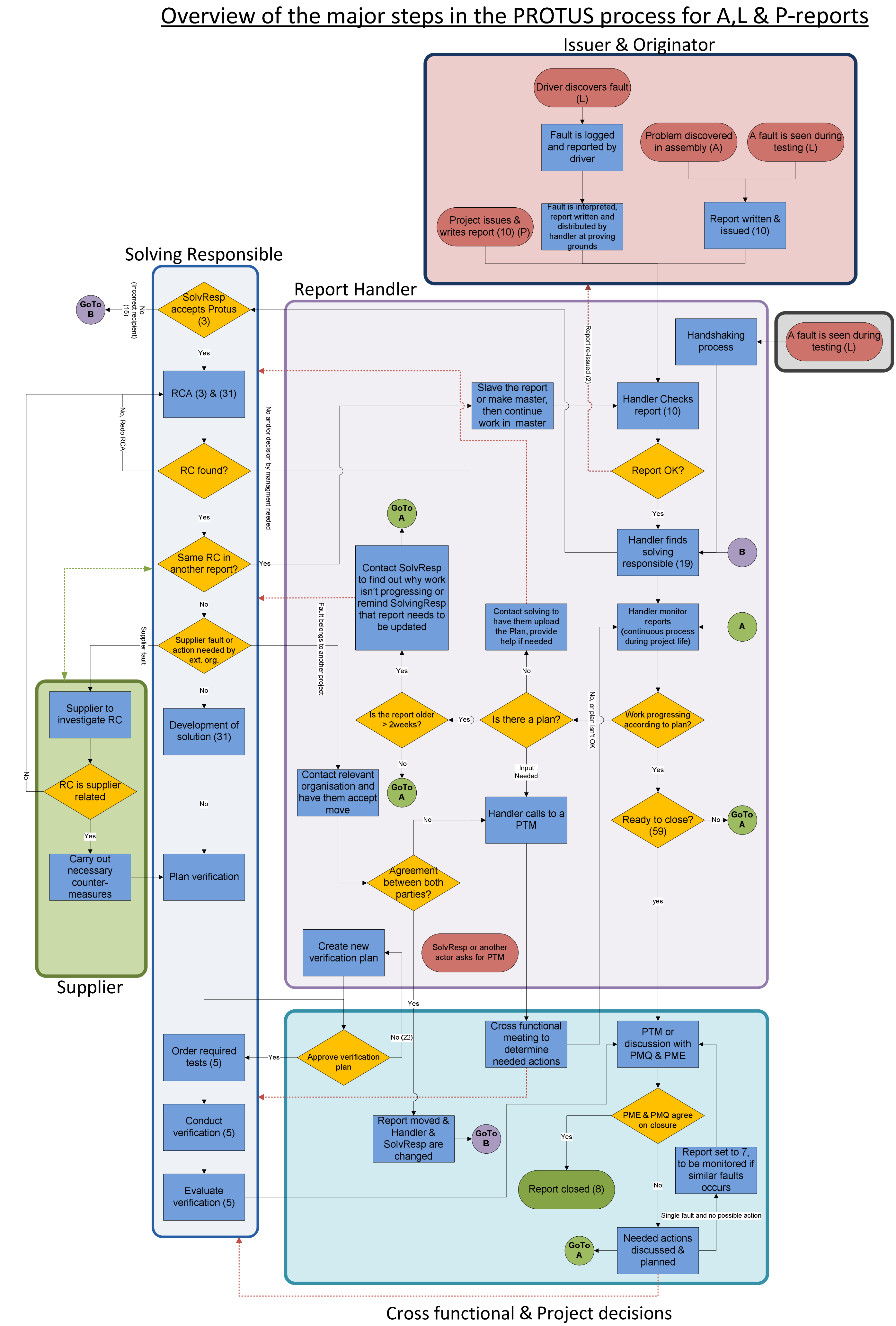

Figure 8. Process map of the failure reporting process

4.3 Report issuing and structure

The PROTUS reports are divided into four categories: Assembly reports (called A reports within Volvo), Project reports (P reports), Lab reports (L reports) and Factory reports (F reports). A, L and P reports are handled within the same process while F reports are handled separately and are therefore outside the scope of this study.

- **Assembly report**: Report covering assembly related issues, normally issued by Operations, input from Operations is needed during verification.
- **Lab report**: Report originating from a test activity, for example from a test cell, proving grounds, simulation or a field test.
- **Project report:** Report initiated by a project due to a failure or a potential problem and reports issued on product properties. These reports do not have to be tied to a specific part number.

The originator grades the report according to a fault point flowchart, set by consulting an audit manual. The fault point rating can be set to 1, 5, 25 or 100 points depending on the consequences that the fault is assumed to have; a high fault point rating indicates that the problem will have a high impact on product performance and/or manufacturing. One of the interviewees also mentioned that using the fault points to prioritize reports can be misleading since they do not necessarily indicate the impact that the report has on the project. Throughout the interviews some SR also mentioned that the fault points do not say much about how difficult the task is to resolve and therefore is not always a suitable indicator for how severe the report is and how much attention that it needs. Should for example a report with high fault point rating but with a trivial solution receive more attention than a report with a low rating but with a diffuse fault description?

When issuing the report the issuer enters the required information into a mix of free form text fields and structured fields. The fields to be filled in vary depending on the type of report; an example of the different fields that are to be filled in an L report can be seen in Figure 9. Among these there are a few fields that are worth mentioning in more detail:

- Part number: Reports in PROTUS are directly linked to a specific single part through a unique part number; a part number represents the lowest level building block used when manufacturing a vehicle.
- Object number: The number of the project in which the fault occurred.
- Responsible object number: The number of the project that the fault belongs to i.e. the owner of the problem.
- Description: A free form text field where the encountered problem should be described.
- Design group: The group responsible for the design of the object.

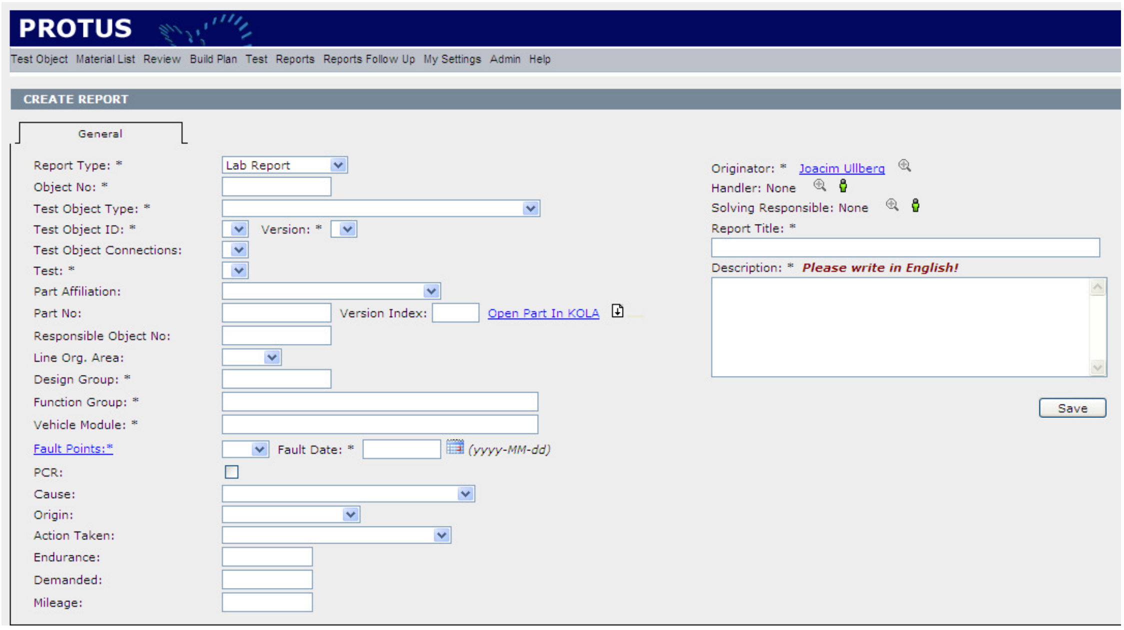

Figure 9. Example of report creation of an l-report where all the fields that can be filled in can be seen (Screenshot from PROTUS)

To support the solving process it is also possible to attach and to upload various file types to the report that could prove useful for the SR, such as documents, pictures, movies, log files, etc. Each report that is to be created should be tied to a single fault; reoccurring faults can be reported as a fault several times for each time it has occurred.

When the issuer has completed the report the report is sent and distributed by the issuer and the report is stored in the PROTUS database, and a notification e-mail is sent to all members on the distribution list. The distribution list consists of an automatically generated list of stakeholders and subscribers to the system. One of the strengths with the system according to one of the interviewed SR is that once a fault has been entered into the system the problem has to be addressed.

4.3.1 Report issuers and their procedures

There are a few actors related to PE Göteborg who normally issue reports related to PE. The test cells located in close proximity to the Göteborg site, Volvo's proving grounds; one of Volvos main test sites for complete vehicles, the projects themselves and a manufacturing plant located in Skövde responsible for assembling the majority of the prototype engines used during product development.

A PROTUS report hailing from the proving grounds is usually not issued by the originator; instead there is a team working solely with interpreting deviation reports from the truck drivers who based on these reports writes PROTUS reports. The steps to issue a report at the proving grounds are:

1. Test driver encounters or notices a deviation (warning message or codes, something not performing as expected) e.g. automatic lock that is not working,

button that does not work, strange sounds from truck, error messages from the onboard computer.

2. Driver records events with a voice recorder, for clarification he might also take photos or record a video clip. Alternatively the driver adds a note in a notebook about the event.
3. The audio recordings are monitored by a team. They sort and filter the content and will write an L report when they have discovered an issue that has not been reported.
4. They will be considered the issuer of the report and will upload all available data to the report and will also make the initial decision about the severity of the issue.
5. Status is set to 10 (Report written and distributed) and the PROTUS coordinator takes over the responsibility.

The reports written on faults seen during test runs in the test cells are issued by the test engineers. An initial root cause analysis is conducted in order to identify the likely source of the problem and ensure that the report is issued on the responsible part. Reports from Skövde are often related to assembly issues such as the space between two components being too narrow making the assembly difficult, or if the components do not fit in their designated position, the cables are too long or too short, the engine is custom built and therefore all components do not fit, etc.

Neither the official GDI for the PROTUS process nor the internal process description for PE offers any guidance of what a fault is and what types of faults should be reported in the system. However, they do mention how the faults should be reported and graded. What constitutes a fault and therefore should be reported appears to be mainly a matter of opinion. This was later reinforced by one of the coordinators who said that there is no definition on what a fault is; a fault is something that someone believes is wrong. The projects themselves have no say in the matter, but they can decide on how to handle them.

From our observations this can at times lead to some frustration as one of the interviewed SR exemplified. He mentioned that he at one point received a high amount of reports from Operations, each covering a known deviation in the CAD files. We have seen that reports based on CAD files often only concern poor representations in the files, where there for instance could be gaps between components, and that these issues will not materialize into problems in the end product. The aforementioned interviewee felt that these types of problems should not have been reported in the first place since fixing these deviations is part of the normal design work carried out and the end result was that he had to spend a lot of time administrating and updating the PROTUS reports instead of concentrating on his real work while the group statistics suffered. Based on an interview with a coordinator it appears that the projects do have internal CAD checks as part of their working process and that the severity of the CAD issues depends on the component version. A CAD issue could be severe if the part would enter production without being corrected. One of the reasons according to the same interviewee is that

Operations are not involved to any higher extent in this process; instead operations can sometimes write reports on CAD faults that they have seen themselves without knowing if the issue already will be handled or not.

A common view regarding issuing of reports is that it is better to issue a report than to avoid issuing a report since the harm of missing a fault likely is greater than issuing one report that might have been unnecessary. But there are also contrasting views from interviewees regarding this point. One subsystem manager said *"I sometimes wonder if it is too easy to create a PROTUS report. Sometimes it might be enough just to check with component responsible"*.

4.3.2 PROTUS system structure

Apart from the main tab with general information about the fault which is entered when the report is created, the report also has tabs for the action plan, technical comments, uploaded files, distribution and history. Inside the action plan tab there is a free form text field for the root cause and one for the technical solution. The report can be viewed in two different modes; an edit mode and a static mode. In the static mode the visibility for some text fields is better and text that cannot be seen due to longer text than the size of the edit windows are fully visible in the static version. However the most common way to view reports appears to be through the edit mode.

The action plan tab as can be seen in Figure 11 contains information about the root cause which can be entered into a free form text field, the technical solution and planned dates for important activities. Several of the interviewees have expressed a wish for a larger window to enter the root cause into, since as it is today it is too small forcing the user to either write a short root cause or to have the text partly hidden when it becomes too long. One interviewee also stated that this sometimes can lead to that the descriptions of the root causes become less detailed than they otherwise would have been.

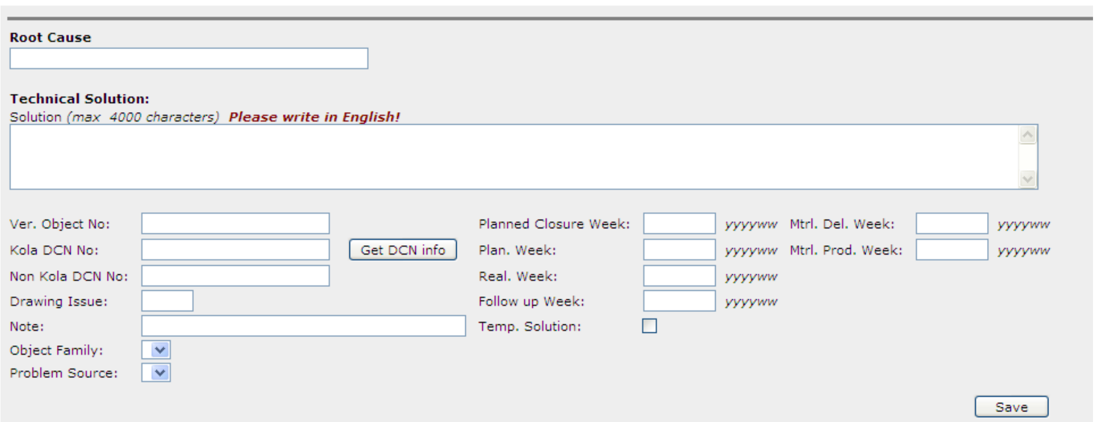

Figure 10. PROTUS action plan tab (Screenshot from PROTUS)

The technical comments section is used for discussion about the problem and for documenting ongoing activities and results from PROTUS team meetings where the problem is discussed and the changes in the reports are commented. It is basically a non-editable forum in which anyone with access to PROTUS can post a comment. The technical comment section is frequently used during the entire lifetime of the report. The SR usually uses the Technical comment section for documenting their work and how the work is progressing. It is also often used by both the SR and by other stakeholders for reporting progress.

It was often seen that in long reports the technical comments section becomes difficult to follow and it can at times be difficult to sort out the information stored that is of value. The technical comments found in the system also do not always strictly concern the progress towards resolving the issues, sometimes making it difficult to find relevant information, for example when discussing the reports at PTMs. It was also observed that considerable time was spent at PTMs searching for the right information. Since it is not possible to modify the comments unintentional errors can often be found, which can be both misleading and lead to some confusion during the PTMs when the time is short and there is a lot of information to gain insight from.

4.4 Resolving the problem

Usually an engineer is notified of the report trough an e-mail, informing them that they have been set as SR and provides them with a link to the report. Once a SR receives a report they are expected to look at the report and accept it. If the information provided in the report is deemed to be insufficient the SR has two options; either to put the report in status 15 (*Report has not reached correct solving responsible*) and/or to contact the issuer for more information. At PE the most common procedure observed was to contact the issuer without a changing the status. How the contact is made is up to the SR, and various ways have been observed including a question written in the technical comment section of the report, direct contact, or contact by phone or by e-mail. Coming in contact with the originator can sometimes be more difficult since the originator's name often is not listed in the report. This has also regularly been observed in reports originating from the proving grounds where the driver's name often is not stated in the report.

From the interviews it was revealed that the SR sometimes receive information about the fault before a report has been created, for example by being contacted by a test cell operator or test cell engineer. One interviewee also stated that he viewed PROTUS mostly as an administrative tool which is used to let the project know what is going on more than it being helpful in his work with the problem.

A reoccurring comment in the interviews with the SR was that the description of the fault written by the originator often did not provide sufficient information needed in order for them to start investigating the fault. One interviewee stated that while it had become common to put pictures in the report, the pictures often were not of much help to him. The pictures were often taken in a manner that made it difficult for him to identify the fault, often the pictures where too zoomed in or too zoomed out for him to either be able to observe the fault or to put it in a context. For example a picture on a faulty screw could be so zoomed in that it becomes difficult to tell which screw the picture is showing since there can be several identical screws present. A suggestion made was that the issuer should become better at marking where in the picture the fault has occurred. The same interviewee also said that lack of information in the report or unclear and diffuse information can aside from preventing the work to start also result in work progressing in the wrong direction, resulting in wasted time and longer lead times. This is also backed up by another interviewee who stated that some reports appear to be written in a hurry, which leads to more work for the SR. for example the description of the fault can be given in just a single sentence such as "*cable is too short*" or "*cable does not work properly*".

4.4.1 Action plan

There are two things that the project demands from the SR early on in the process: An action plan describing what is to be done and when the deliveries will occur and secondly to set a closure week for the report. The closure week (CW) is supposed to be based on an action plan; however this is not always the case. There is no clear definition on what should be included in an action plan and there appears to be two different views regarding what is to be included. One is that that an action plan should describe what the current plan for dealing with the report is, another is that the plan should be based on the root cause and describe the activities needed to close the report.

When inquired about the CW and action plan a majority of the interviewed SR mentioned that they nowadays feel like the projects demand a CW to be set on reports early on. Normally the projects themselves consider a report with a set CW to have a plan that supports the set CW, which usually means that they want all reports to have a set CW within two weeks from when the SR receives the report. If there is a closure week the project is happy if not they will start to complain about it.

One interviewee mentioned that it is better to have it planned even when you do not have an actual which according to the same interviewee also felt wrong, but was still the way he would act if the project would demand a plan for one of his reports. Another interviewee said that it is unreasonable to demand CW early on in some cases, for example it is not possible to always initiate the RCA immediately since they would have to stop a running test in order to check the component and problems can also be diffuse making it difficult to predict the time needed to resolve the fault.

"The demand is one thing and the way we work another thing"

The same interviewee also mentioned that *"thinking about setting a CW gets you to think about what is possible, but at the same time that is something that I already have done"*. Several of the interviewed SR said that they felt pressured by the projects to set a closure week even when there is no substance behind the number.

One of the coordinators' view was that the closure week should be set when it is possible to make estimations of the time needed and therefore suggested that a closure week should be set first when the root cause is known. He further argued that when the root cause is known it is usually easier to estimate the time needed to resolve the fault since then it becomes easier to predict the time needed for verification and for designing a solution. Before knowing the cause it is for the most time difficult to estimate the course of actions needed in order to mitigate the fault and therefore the time required to resolve the fault. Today the SR is usually given some time (today about two weeks) to respond and to act upon the fault before the project reacts on an unplanned report or a report in status 19 (Report has reached correct recipient, handler accepts report).

A difference between the departments observed is that the Control Systems department usually has set dates for a software release and that the design changes are usually tied to these releases and therefore the likely CW by which the solution has to be released is often known and set as the CW for the report while the units not concerned with software releases are not as tied to release dates.

4.4.2 Root cause analysis

When a SR has received the required information they will usually begin with an investigation of the root cause. The procedures for the RCA can take on many forms depending on the problem and the SR conducting the RCA. Currently there is no formal procedure on how an RCA should be conducted and how extensive it should be should be stated in the GDI for the PROTUS failure reporting process. Most of the SRs mentioned that they usually applied unstructured approaches when conducting an RCA. For example, one SR said that he uses *"Logical thinking, there is no need for any tools"*. Several SRs however also mentioned that they felt that most faults were of a fairly simple nature and that the root causes to the problems therefore often were obvious and did not require a deeper level of analysis. Specifically regarding the depth of the RCA one SR told us that "*The level of the RCA is only done at a level deep enough to solve the problem. Due to time constraints it is not possible to work for the future"*.

When the RCA indicates that the fault is the same as already mentioned in another report they can be linked together through a procedure called slaving. Slaving a report means that the report being slaved will become frozen and disappear from normal searches and from most of the statistical summaries created by the projects and PE, and instead it will be listed as a slaved report in the master report. A master report is a report that contains one or more slaved reports. Sometimes it is later revealed that the master and the slave do not share the same RC, and in these cases the slave has to be released again. This can be problematic since releasing a slave will unlink all reports slaved to the master regardless of the RC. Aside from SR suggesting that a report should be slaved this is also sometimes done based on the request from an issuer.

When the fault is related to a component manufactured by a supplier and the cause appears to be in their processes or design the SR is expected to manage the contact with the supplier. In these cases the supplier often conducts their own root-cause analysis in order to identify the cause, which often is conducted through following the procedure of an 8D-approach (Eight disciplines approach, a model used for problem solving).

4.4.3 Verification

A solution to a problem must always undergo some kind of verification before the problem can be considered resolved. This is done in order to ensure that the suggested solution solves the problem and that the root cause to the problem has been found. A common requirement for the verification is that it should be performed on the test object (for example an engine, gearbox, or truck) where the fault first was found and in the case that the failure occurred during a test run for example in a test cell it is often required that the new design should pass the same test that it previously failed in before the solution can be accepted. In the case of assembly reports the verification has to be approved by Operations in order for the verification to be accepted. Discussions about how to verify solutions can become hotly debated subjects during the PROTUS team meetings.

Sometimes, however, faults occur where no more fault tracing can be done, or where the underlying root cause cannot be found. An example of this scenario was a PROTUS report where the failure occurred due to a missing screw, and while the connection between the missing screw and the failure was clear it was not possible to further investigate when the screw went missing in the first place, since it was not possible to trace where the screw had gone missing. When these types of failures occur there are basically two options available to the project. One possible path is to close the report without further action. Another more common approach is to put the report in status 7 (*no action at present*) indicating that no further action will be taken at present and then follow up the report again at a PROTUS team meeting after a certain time has passed. The report can then be closed at the follow-up meeting if no further complications or similar faults have occurred.

Some of the interviewees mentioned that the verification phase is the most time consuming part of the solving process in terms of the amount of weeks that the report spends in a certain phase. According to them there are several reasons for this including the time required to build a new engine to test on and finding a suitable engine to conduct the verification on. Some tests also take long time to run, such as durability test runs that might be needed in order to ensure that the new part survives in the same climate as in which the previous part failed.

4.4.4 Closing the report

Following the completion of the verification phase the solution has to be accepted by the project in order for the report to be closed. This is either done during a PTM or at an unofficial meeting between the PMQ and PME as the agreement between the PMQ and the PME is the criterion for closing the report. The decision to close a report or to keep it open can however be overruled by the CPM. What is required for a report to be brought up for closure is not clearly defined. For the PMQ and the PME to agree on closure most often a successful verification and a solution to the problem the project is facing are needed, also in cases of design changes a DCN has to be released. The reason to why the PME and the PMQ have to agree on closure is that they represent different functions of the project management team and that both areas have to be satisfied with the solution in order for the solution to be considered satisfactory for the project.

To simplify report closure and to make it clear what is needed to be done in order to close the report, the project can define a set of closure criteria for a report. These closure criteria are normally defined during a PTM together with the SR. Common criteria include type of verification needed for the solution, DCN being released, on what engines/trucks the solutions should be verified or solved. Closure criteria can be set at any time during the report life time, as there is no definition on when they should be set and what should be included. Today the setting of closure criteria is done infrequently, and most of the reports that we have seen do not have predefined closure criteria when they are closed.

One of the interviewed SR mentioned that information on what actually is required before closing is not clear and further said that a checklist for PROTUS describing general guidelines for report closure would be good. Another interviewee mentioned that it would be good to have set closure criteria earlier on in the process since when the goals are clear it becomes easier to work towards them.

4.4.5 PROTUS team meeting

The PROTUS Team Meeting (PTM) is a cross functional meeting held as a forum for closing reports, accepting verification plans and for making decisions related to the reports for which decisions or input from the project management is needed. Participants from the projects include the handler who leads the meeting, owns the agenda and is responsible for documenting the decisions, the PMQ and the PME who are needed for decision making. Other participants called to the meeting include the SR whose reports are on the agenda, and sometimes a contact from Operations, usually a PMO (Project Manager Operations). Each meeting has an agenda often consisting of several reports. The time available for each report is typically limited to about ten minutes and therefore the PTM is not supposed to be used for discussions about the problem or the report.

However the reality of today differs somewhat from the intended use of these meetings described above. From our observations we saw that a common problem with the meetings was a low attendance of key participants. From the management side this included both the PMQ and PME, who many times were busy and therefore did not have time to go to the meetings, which in the worst case resulted in a situation were no decisions could be made during the meetings since the decision makers were not present. One interviewee commented: "*Sometimes you go to the meeting and there is only a PROTUS coordinator*". Another problem was that the SR did not always show up to the meetings making it difficult to make any sort of decision related to the report since the information found in the reports, even if recently updated, did not alone provide the needed level of information for a decision to be made.

From the interviews it appeared as if the purpose of the PTM is often not fully understood as it is today and there are several opinions regarding both what they are there for and to what extent they add value to the process. Some of the SR view the meetings as a way to discuss the problem and sometimes get new ideas or help with the problem, while another view was that the PTM is mostly a way to report to the project about their progress and as such the PTMs added no value to their work with the problem. Some interviewees also mentioned that they felt that it is pointless to go to them when neither the PMQ nor the PME is present. A common wish uttered by SR was for there to be some experienced employee present at the meetings who can provide input on how problems could be solved and how similar issues have been handled earlier.

4.4.6 Group level management

When questioned about how the design groups handle the reports and support the SR with their reports, overall the most common response was that the reports belonging to the deigns groups were discussed once a week during the groups' reoccurring DTL (daily team leadership) meetings. The DTL meetings are reoccurring meetings, often held several times a week, at which the daily and/or weekly activities of the group are discussed. The groups' members will during these meetings report and shortly describe their current activities, their deliveries and how they are progressing with their tasks. They also provide the groups' members with the opportunity to elevate and highlight issues that they are currently facing. Normally the reports with an upcoming CW, reports that already have passed their CWs and unplanned reports are highlighted during the DTLs. Not much time is given during the DTLs to discuss the issues; however the design engineers are free to seek support from their group managers or their group members to discuss the issues further.

4.5 PROTUS Performance Measurements

The PROTUS system can present a number of statistics regarding the reports it contains. Via a report follow-up section in the system, it is possible to retrieve graphs showing the reports sorted by projects, statuses, dates, fault points, design groups and function groups. Lead times between all statuses can be seen for both open and closed reports; however it is not possible to see the time reports have been in their current status. These lead time figures only include those reports that have been set to those statuses specified when searching, and do not include reports which have been set directly to a higher status. For instance, if you want to see the average lead times for reports between status three and five a certain week, the system will not include reports that have had their status switched directly from status 3 (*Investigation and work on solution*) to 8 (*report closed*).

4.5.1 Powertrain

This year, the Quality, Processes & IT department at GTT PE has set up a PROTUS performance site on the local network, which presents a set of measurements for GTT PE in total and for the different sites. The set includes quantitative data directly from the PROTUS system, and derived statistics on the percentage of reports which have had a submitted root cause that is deemed to be at a sufficiently deep level, and what percentage of the reports have been solved through systematic use of solving tools. The measures concerning root causes and problem solving tools have been gathered by the head of the department who has selected a sample of reports which have been judged based on his opinions. The measurements shown on the site are presented in Table 5.

Table 5. Measurements shown on Quality, Processes & IT's PROTUS site

Category	Measurement
General Performance Indicators	Number of open reports (ALP) Number of open 100 p reports (ALP) Number of open reports older than x weeks (ALP) Number of open reports older than y weeks (ALP) Number of open reports older than z weeks (ALP)
Problem Solving Performance Indicators	Percentage of Root Causes registered (closed) Percentage of Root Causes registered (status 39) Technical Root Cause identified Systematic use of problem solving tools
Planning Performance Indicators	Number of Reports unplanned older than 4 weeks Percentage of Reports closed on time Percentage of Reports planned before closure Number of Rescheduled Closure weeks
Leadtime Performance Indicators	Leadtime status 1-3 Leadtime status 1-39 Leadtime status 1-8

Not all of these measurements have been used as bases for decisions, but the number of reports older than three years has triggered an effort to examine them and close them. The reason for this is that these reports are believed to be left and are no longer active, and they result in the lead time measurements being skewed since these reports are not representative. The percentage of root causes registered and their quality along with the number of unplanned reports, closures on time and rescheduled closure weeks have led to a decision to examine the PROTUS process further, e.g. through this thesis.

4.5.2 Project measurements

In one major project, the PROTUS coordinator makes a report covering the current PROTUS state weekly, which is presented at a project review meeting. This report presents how many reports are open in total and how many of those have not resulted in a planned DCN (status 10-35) and how many of which are 25 or 100 point reports. It also presents the number of reports that have been closed and opened last week, how many that were supposed to be closed according to their closure week, how many whose closure week has passed and how many reports older than two weeks that do not have a set closure week, which they consider unplanned. The project uses graphs to illustrate how these measures vary over time. This graph also illustrates future predictions on how the status count will evolve over time based on the closure weeks found in the current active reports. It does, however, not predict the inflow of future reports, which results in an ever declining future curve.

Most of these figures are directly extracted from the PROTUS database and can be seen by anyone who has access to PROTUS. The numbers of late and unplanned reports, however, must be gathered through sorting an Excel file of the reports which is imported from the system. Additionally, a selection of "top PROTUS reports" is presented in a list in order to keep the project management updated on the most important issues. This list is assembled by the coordinator who picks reports based on fault points and how difficult the reports are to solve as perceived by the SR. In another, smaller, project the coordinator similarly makes a report weekly, but instead only includes a graph showing the number of reports combined with a curve showing the preceding project's amount of reports. The PROTUS target in this project is to always have fewer reports than in the preceding project in the same stages of the project. If the target is not met, the PME of the project will ask for more resources in terms of test runs and engineering hours. The PME of this project said that it is good to see a decline in PROTUS reports, but at the same time it is good when the number increases in that you then become aware of problems you did not know existed earlier. He also added that he prefers to see one report too many than one report too few. In a third project, which is more directly working with vehicle engineering, the procedure is different. Here, the PME makes a report similar to the aforementioned, and sends the report to VE for review where feedback is received based on VE's process requirements.

On subsystem level, measures are used in different ways. In one of the projects at Control Systems, a graphical presentation of their current PROTUS state is constructed weekly, similar to the one for the project level of the project mentioned first in this section. At Base engine, the PL for the same project assembles an Excel file at the start of each week, with all reports that are planned to be closed in the current week, and the ones whose planned closure week have passed. Based on this list, the PL plans discussions with the SR of those reports to see if they are progressing, or if they need more time. If they conclude that the report cannot be closed in the ongoing week, the PL tells the PROTUS coordinator not to invite the responsible to the PROTUS meeting.

Based on both the interviews and observations we have seen that the focus on PROTUS increases when the project approaches one of the stage gates used to determine if the project is ready to pass on to the next stage of the GDP, since the gate only can be passed if the number of unresolved reports belonging to a project is below a certain threshold. The manager of Base Engine said that they have a general target of having at most 15 open PROTUS reports when a project passes one of the stage gates, but added that it is not always easy to identify whether this is achieved or not. This due to the definition of what constitutes a project being unclear, as larger projects can include sub-projects in which case the target can be met or not met depending on what level is evaluated.

According to our observations and the interviews it became clear that the measurements addressed most frequently were the number of open reports, unplanned reports, late reports and closures per week, and these were also the only measurements mentioned by SRs when asked about which ones they were aware of. If the number of closures was lower than normal one week or when there were many late reports, attention from the project and subsystem management was directed more towards the late reports or reports that were near being able to be closed rather than recently submitted ones. When there were unplanned reports, these received extra attention until a closure week was set. Additionally, the reports with 25 or 100 fault points are generally prioritized. Several SRs stated that the focus on closing reports quickly sometimes meant that closures were hasted, having consequences on the quality.

4.6 Different PROTUS procedures

The procedure for resolving a PROTUS varies within Volvo. For example Volvo GTT VE uses a different procedure than PE when handling and solving the PROTUS reports, yet the purposes and the objectives of the processes are the same. The differences between PE and VE include the way the reports are closed. In the VE organization the PMQ and PME are not involved in the closing procedure, instead this is done on a lower level within the responsible line organization unit. At VE the issuer also has to accept the solution before the report can be closed. At VE the handler also plays a different role than at PE. VE does not use global project coordinators, instead the handler role is filled by the line mangers which according to a PE coordinator can results in a project organization that has less insight into the problems and how they are dealt with.

From our observations and the interviews we have also found that there are differences in how PROTUS is managed between the internal projects at Volvo GTT PE. One of PE's major projects today has made two major changes to the process. They have introduced a PROTUS Opening Meeting normally held once a week with the objective to check and to direct the reports to the correct SR. The participants include the handler and affected group managers. Another change that this project has introduced is to handle the reports differently depending on their fault point rating. Reports with 25 or 100 fault points are handled the ordinary way, while reports with lower fault point ratings have local team managers set as handlers. This change was introduced to reduce the burden for the handler working with the project and to reduce the distance between the handler and the engineer set as SR. This way most of the decisions are made without the project's direct involvement.

4.7 Training and documentation

When the interviewees were inquired about the training and supporting documentation available it became clear that a majority of the interviewed SRs had not received any training or instructions on how to use PROTUS. Instead they mentioned that a common way to learn things were through trial and error and by asking their colleagues for help. Several of the interviewees mentioned that they had never seen any documentation regarding the PROTUS process but most of them stated that they believed that it existed and could be found if they decided to look for it. Regarding training about RCA not a single interviewee mentioned when asked that they had received any specific training for it.

When asked about how they would use documentation describing the process if made available there were various responses. Among them one interviewee mentioned that he would not spend time to search for documentation he did not believe that he needed and knew that it existed. Another interviewee said that a simple checklist would be helpful as a guide if it was easily available. One of the interviewed SRs also stated that the process is simple enough that no training is needed.

The internal documentation describing the PROTUS process is primarily located at two locations, the PROTUS portal and its support page and PE's system for process documentation. The process descriptions found for PROTUS are mainly concerned with the flow of the reports and how the reports should be administrated, including handoffs and handshaking procedures for the reports. Not much is described about the goals, procedures and activities that are needed from each involved stakeholder in the process in order to resolve the fault. The activity of identifying the root cause(s) and required procedures for this activity are not given any attention, rather focus is on the flow of the report and that the correct unit is handling the issue. A figure describing Volvo's view can be seen in Figure 11.

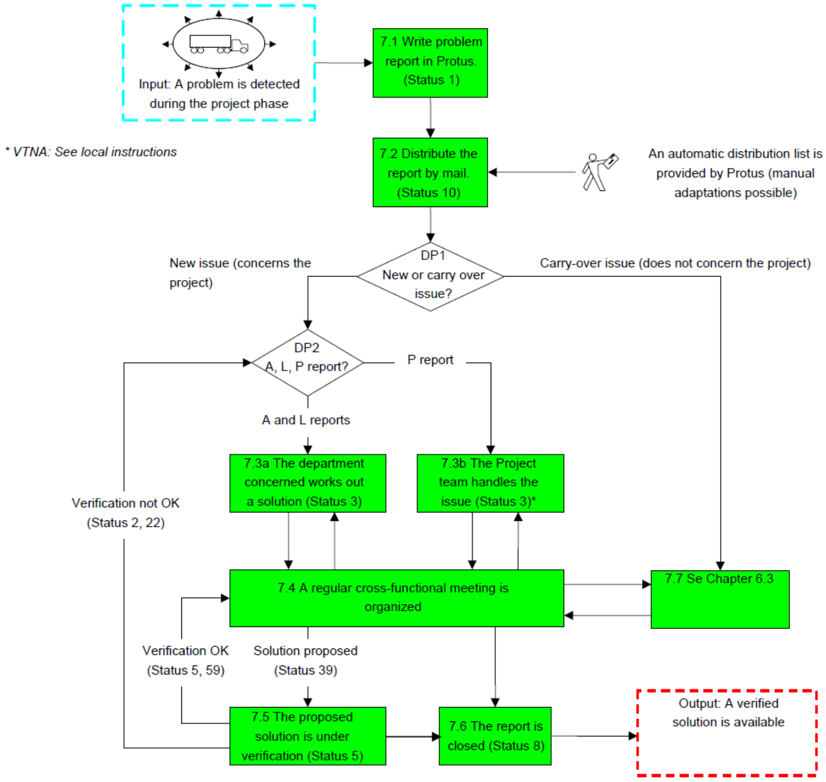

Figure 11. Flowchart of the failure reporting process (AB Volvo, 2009)

4.8 Process improvement and learning from PROTUS

During our observations of the PROTUS process we did not see many efforts to ensure that faults do not reoccur or process modifications based on findings in PROTUS reports. However, we saw one case where a new procedure was to be included in the project plans after having concluded that three reports had emerged as a result from a test engine and rig not having been cleaned after an earlier test run. There is however no defined standard way of proceeding with correcting underlying causes to problems reported in PROTUS, and the underlying causes that led to the development of a component or system having a fault was rarely asked for at the PROTUS meetings. One interviewee also said that there is no time for deeper root cause analyses than what is required to adjust the fault in the ongoing project, and the responsibility to learn lies solely on the line organization. One SR responded to the question on whether he worked on preventing future failures based on PROTUS reports by saying *"I've never really thought about it in that way"*.

According to most interviewees only individual learning occurs from the PROTUS process, while a few stated that knowledge and experiences are spread by talking with other employees and sharing what has been learned from working with the reports. When asked about if there are any available methods to utilize knowledge from past projects other than by remembering personally, several interviewees mentioned a document called Design and Verification Guidelines (DVG), in which experiences shall be written down and why certain changes to a component have been made. However, none of the SR interviewees said that they actively used this when entering a new project. A group manager said however that this is something that he has seen being used by a few engineers, but that it is mostly used by new inexperienced employees and not by those with more experience. One section manager, however, said in contrast that DVG is something that is widely used by engineers when designing new components. Most of the more experienced interviewees stated that they have seen fault reoccurring throughout the years, and this was also commented by a section manager who said that:

"*Every seven years the same concept fault reoccurs, since by that time all developers within that area have been replaced*"

When the SRs were asked why the DVG is not used more extensively, all respondents referred to lack of sufficient time to plan the development in the early phase of a project. The section manager who believed that the DVG was used frequently suggested that a new step in the PROTUS process could be included in which you examine whether the fault in the report was covered in the DVG for the related component. He also believed that the subsystems could be better at initiating 3C reports (a procedure used for process improvement) when discovering issues that could be prevented by working in a different way.

Part V: Analysis

"Quality is not an act. It is a habit"
Aristotle

In this chapter the results from the empirical study is analyzed through the use of the theoretical framework. The analysis is divided into principles, practices and tools.

5 Analysis

This chapter is divided into three sections named principles, practices and tools. In the principles section, the purpose of the PROTUS process and its desired effects are discussed. In the practices section, the activities that link the principles to the available tools are addressed, and in the tools section the tools used when practicing the process are analyzed. This results in a collection of findings that aims at fulfilling the report's purpose that is "*to design a process for reporting, using and following up prototype failure data in a way that enables continuous improvement in the product development process*".

5.1 Principles

A starting point for an analysis of the PROTUS process is to determine what effects it is aimed to have in the studied environment i.e. GTT PE. It is therefore necessary to identify the intended suppliers, input, output and customers and what requirements there are for them to fulfill the purpose. Today it is clear that the purpose of the process is not fully known and shared throughout the organization, where some engineers perceive it as merely a reporting process for the project, whereas others think that it is an essential tool for product development.

AB Volvo (2009) defines the purpose of the PROTUS system as a means to *"[…] ensure the right product quality by means of systematic and global uniform handling and documentations of faults arising in connection with product development and prioritization of problem solving"*. However this definition is only concerned with how faults should be handled within the PROTUS system and not the ultimate goal of the process. Knowing who the customers are and their requirements are according to Bergman & Klefsjö (2010) essential parts of TQM, where they place these factors under the **Focus on the customer** cornerstone. The only customers to the current PROTUS process that are widely recognized today are the projects, who desire to solve problems within their areas. There is no emphasis on learning or improving processes, of which all parts of the organization are potential customers.

Lengnick-Hall (1996) speaks of customers having different roles, and this is certainly the case in the PROTUS process. As a few of the interviewed engineers regarded the PROTUS process as a tool in their development work, you could say that both the projects and the line organizations can be seen as customers as well as co-producers in that they partake in the solving efforts. You could argue that all parties involved in the process can at different times possess all of the different roles presented by Lengnick-Hall (1996). The projects act as purchasers of the solving of problems, resources that give input in the form of guidance and expertise from the PME and PMQ, users of the results in the end product and in the remainder of the product development within the project. The line organization naturally also uses the results in their future development and provides engineering efforts, but they are ideally also transformed by the product in that they have achieved learning.

In order to support quality improvement and learning, and combine this with the demand for resolving issues quickly, which is stressed by the projects today, one should according to Ferdows & De Meyer (1990) primarily focus on the quality dimension before other ones such as dependability, speed and cost efficiency. This is not always the case in today's process at Volvo. Several interviewees suggested that the projects demand fast closures of reports, sometimes having consequences on the quality of the work, despite the inclusion of PMQs. While Skinner (1966) argues that there are trade-offs in the performance dimensions, and that the speed could suffer from focusing on quality, later research points toward quality being a prerequisite for excellence in the other dimensions (Ferdows & De Meyer, 1990; Nakane, 1986). This suggests that the view of the PROTUS process is not optimal and that focus should be changed.

Improving the PROTUS process and learning from the PROTUS work does not seem to be rooted in the organization. When asked about it most interviewees stated that only individual learning is done, and that there is no time for getting to the bottom of what caused failures to be developed into the products. One interviewee who has worked at Volvo for two years responded when asked about preventing future failures that "*I've never really thought about it in that way*". This suggests that the full intended aim of the PROTUS process has not been communicated clearly enough throughout the organization and can also be related to the fact that the current aim of the process is lacking in regards of actually satisfying the closed-loop requirement that is part of the FRACAS objective. Another reason that plays a factor could be that process improvements must not have been asked for during PROTUS meetings. Wheelwright & Clark (1992) argue that it is difficult to learn from the sources with greatest potential for learning, since the most important performance can be a result from complex interactions, and that learning does not occur naturally even if outcomes of projects are successful. This suggests that some kind of mechanism should be put in place in the process to incorporate learning as a natural feature.

5.2 Practices

The current practices at Volvo are in many ways comparable to the existing FRACAS frameworks that have been identified in the literature review. In comparison to the framework presented by Lee, Chan and Jang (2010), previously presented in Table 4, which represents the most detailed of the three frameworks found there are some differences compared to the current practices at Volvo. First of all, all the task and activities in the PROTUS process are not clearly defined and described in the existing documentation and process maps. They are instead mostly concerned with the procedures for the reports themselves and how they should be dealt with in a systematic way; therefore the process maps as they are defined today are not directly comparable to the FRACAS frameworks. The FRACAS frameworks do not focus on the reports but rather on the steps and activities required to ensure that a satisfactory solution to the problem has been reached, where a satisfactory solution can be seen as one in which the problem has been addressed on a level deep enough in the organization so that a similar problem will not occur again. While therefore not all activities and steps in PROTUS are officially defined it could however be argued that the inherent variety of the process makes it according to Slack, Chambers & Johnston (2007) difficult to fully standardize and specify work tasks and activities. The common activities observed in the PROTUS process in the interviews are however comparable to frameworks presented.

Apart from the task that corresponds to the current way of doing things there are some tasks that are partly missing in the PROTUS process.

Task 3 Verify Failure which is not explicitly asked for and appears not always to be done. Here the difference appears to be partly dependent on where the report has been issued from.

Task 4 Isolate the lowest leveled suspect item which is to isolate the lowest leveled suspect item, is not always done since the current system implementation always forces the issuer to report on the lowest possible level even if the fault is only isolated to a higher level of components. Which is an issue that has been reported as problematic by some of SRs since this according to them can make it difficult to address the faults to the correct recipient and make it more difficult to work with system faults since the focus is then set on the wrong level.

Task 8 Search for similar failure history this is not done today unless the SR or someone else remembers a similar fault.

When comparing the results of the PROTUS process with the objective of the FRACAS system which is to act as a closed-loop failure reporting system, it becomes evident that the PROTUS process itself does not fully fulfill this definition since the PROTUS process does not ensure that the failures are dealt with in a manner that prevents reoccurrence and therefore the closed loop requirement is not fulfilled.

5.2.1 Process input

What has been seen throughout the study is that the input to the process today is varied in nature, leading to unpredictable input. Based on the interviews it appears that the variations in the input mainly is related to the wide variety of the problems the process is set up to handle and the variation between the reports in terms of report quality. The input quality of the data is arguably critical for the performance of the process and the ability of the process to take the needed corrective actions. This is addressed by Hallquist & Schick (2004) who argues that one of the key points to a successful FRACAS implementation is the gathering and reporting of meaningful data. Hallquist & Schick (2004) also presents ineffective and inefficient data tracking as one of the three common issues that often plagues a FRACAS implementation.

The input to the process is also important for the process's ability correctly identify and to mitigate the reported problem, since the primary use of the data provided in the report is to support the activities leading the identification of the root cause. As unclear data as argued by (Bhaumik, 2010) not only risks leading to a prolonged RC investigation, but also can result in faulty conclusions regarding the cause and thereby impact the outcome of the process. Therefore missing or incorrect information could affect the entire chain of activities that follows the RCA and as such it is important that the quality level of the data is secured.

In a broad sense the input to the process should therefore be meaningful for the RCA in order to be of relevance Bhaumik (2010) and for the input data to reach this level of significance the problem statement should according to Monroe (2010) be of a measurable, observable, manageable and specific nature. For the PROTUS process it appears as if these criteria's are not always fulfilled since the data provided describing the faults sometimes can be diffuse for example "*the cable is to short*" is not even meaningful to the SR. While the interviews with the SRs indicates that there appears to varying perceptions regarding the quality of the reports, it is based on the current available information not possible to fully estimate the impact the this has on the process, since the reports are not the only source that the SR use in order to solve the problem. This also true according to Magniez, Brombacher & Schouten (2009) who argue that the database in itself rarely will provide the information needed in order to conduct the RCA. However, from what has been observed today it is not always that this communication works well today due to several reasons including lack of contact information to the originators of the reports and SRs who use the PROTUS system to try to get more information instead of contacting the needed source directly.

Regarding the information that has to be provided in the report the fact that the SR is not the only customer and user of the reports also has to be considered. There are also apart from the SR other stakeholders who have an interest in the reports and use this information to make decision. Therefore inadequate information in the reports can also result in other problems aside from problems with the RCA, for example it can become difficult for the PME, PMQ or another project representative to get an understanding of the problem and how it impacts the project without a well written problem description.

Throughout the interviews and the observations several potential causes were uncovered for the inadequate information. In Figure 12 a summary of the different causes resulting in inadequate information is illustrated. In this case the information is assumed to be inadequate when the information is unclear, incorrect, or is not detailed enough for the SR to conduct an RCA. What is important in regards to the RCA is that the necessary information is provided to the SR, not that is necessarily is provided in the report.

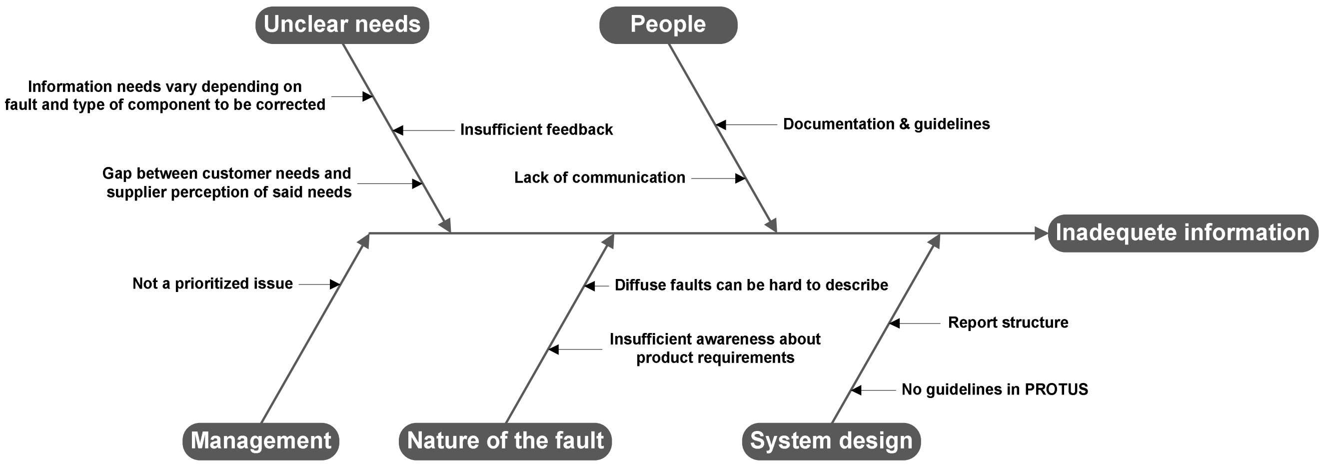

Figure 12. possible causes for insufficient information provided in the reports

5.2.2 Root cause analysis

While the quality of the RCA is important for the outcome of the corrective actions (Monroe, 2010) the response from the interviews indicates the awareness on what the level the RCA should be conducted on is low which could be caused by a lack of instructions and formalized goals on how the RCA should be used in the PROTUS process. Today discussions on what underlying factors that caused reports are rare, and it became evident from the study that there is currently no standardized way in the PROTUS process that aims at sharing knowledge throughout the organization and to prevent faults from reoccurring in following projects. The responsibility to improve the product development processes lies on the subsystems, but there is no defined way of improving processes based on PROTUS experiences. As the PROTUS reports belong to certain projects whose main interest in them is to solve issues regarding their products and close the reports, there is little interest shown in achieving process improvements for the benefit of future development after the projects. From the interviews and throughout the observations several possible causes to the inadequate RCA was identified where in this case an inadequate RCA is a RCA that either does not successfully identify the root cause(s). The different causes uncovered can be found in

Figure 13.

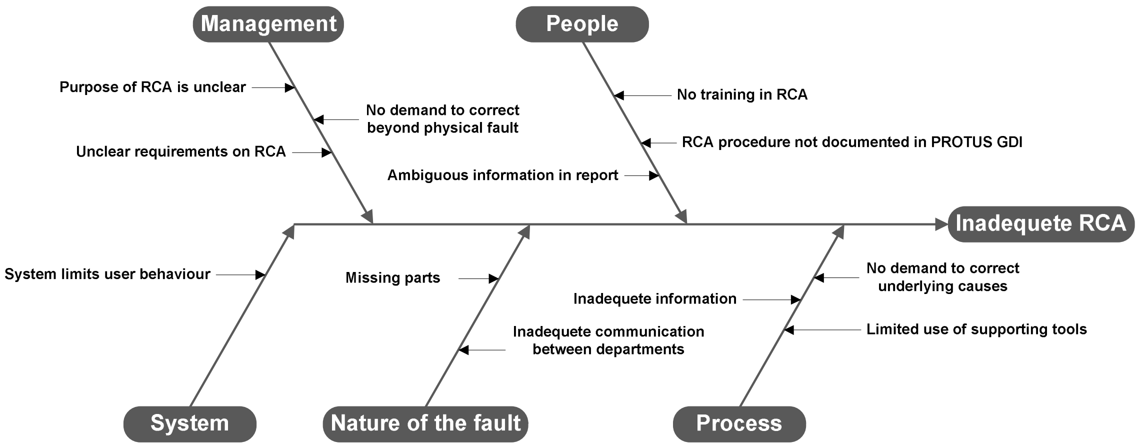

Figure 13. Possible causes for inadequately conducted RCA

5.3 Tools

5.3.1 The PROTUS database

One of the key points to a successful FRACAS implementation is the gathering and reporting of meaningful data (Hallquist & Schick, 2004), and the PROTUS database is the medium in which data are reported, and thus plays a major role in the process. When comparing the PROTUS database to the framework of quality dimensions in knowledge management systems by Mohammad (2010), it performs sufficiently in most of the dimensions. The interviewees said that the system is easy to use and all functions that are needed are present, and the ability to upload pictures was praised, even though the execution is not always optimal. However, the size of the windows have an effect on what is written into them, as is the case with the root cause window receiving shorter descriptions than , which suggests that the system could perform better in the dimension that Mohammad (2010) calls usability.

5.3.2 PROTUS Team Meetings

When looking at a FRACAS framework (Lee, Chan, & Jang, 2010) it is clear that the PROTUS team meetings occur at various steps throughout the process, from when a suspected item has been identified until the corrective action has been incorporated into the products, i.e. when the reports are closed, and they serve as a forum for making decisions on whether or not the process can progress to the following step in the FRACAS framework. Key personnel missing such as PME and PMQ infers waste in the process in the shape of waiting and unnecessary transportation (in terms of SR being summoned to meetings where no decisions can be made) (Bergman & Klefsjö, 2010). Another source of waste at the meetings is unclear closure criteria, which lead to time wasted that would not have been necessary if the criteria had been clear.

One of the cornerstones of Total quality management reads **Committed leadership**, and its implications include personnel commitment and visibility (Bergman & Klefsjö, 2010), for which the PROTUS team meetings provide an opportunity in that it is a structured way of bringing together management with the SR. However, this is of course fruitless if the meeting s lack attendance, and the decisions required for the process to progress suffer, which suggests that effort should be made to increase this attendance.

5.3.3 Measurements for failure reporting

When designing a measurement system the first thing to do according to Franceschini, Galetto & Maisano's (2007) methodology is to identify the process and determine representation targets. What Volvo wishes to achieve with the PROTUS process is to report failures, solve them quickly and achieve improvement while having control of the process so that decisions can be made on where to allocate resources in order to reach targets. The most critical factors of the process that have been identified are the quality of input and the root cause analyses, as basing decisions on facts is a basis for resolving the reported issues according to TQM theory (Bergman & Klefsjö, 2010), and finding the root causes is essential for correcting the faults (Monroe, 2010). Other important factors are the development of solutions, and to have the reports as accurately planned as possible in order to enable predictions for the report status at stage gates, and also that the process must enable the making of decisions that are necessary in order for the reports to be able to follow their plans.

Assuring the quality of input was discussed in the Practices section, but here it is discussed in terms of measurability. It can be troublesome to determine whether or not the quality of issued reports is adequate, as the level of detail required varies from one report to another, depending on the nature of the fault. As there today are no clear definitions on what the fault description shall include, the measurement would be based on subjective judgment by the reviewer, and the indicator would thus not currently be optimal to use (Walsh, 2005). When measuring the quality of the issued reports, it would therefore be appropriate to develop clear criteria for performing the measurement. The root cause analysis factor is similar, in that a review of entered root causes would be based on what the reviewer considers to be appropriate, and also here could a set of criteria be used. These measurements are not very timely (Tuck & Zalesky, 1994), however, as they cannot be directly extracted from the system, but require someone to perform reviews. The lead-times from report issuing to having entered a root cause can be measured and assembled immediately, but this measure could lead to sub-optimization (Tangen, 2003), where root cause analyses are hastily performed in order to reach better values for the lead-time measurement. Therefore, if it is to be used it would be appropriate to pair it with the root cause analysis quality measurement.

As for resource planning, it would be wise to have separate indicators for the number of reports that are open but have not yet reached the verification stage, and those that are in verification and ready to be closed. This due to that the root cause analysis stage and the development of new solution requires most work from the engineer solving the issue, whereas the verification stage mostly involves waiting for test-run slots and the runs. The number of reports in verification and verification lead times could be used for test cell planning. In order to be able to predict report closures the planning must be accurate, and this is an area in which Volvo could improve.

5.3.4 Analysis of measurements at Volvo GTT PE

Based on the measurement system test developed by the U.S. Department of the Treasury that consists of asking different questions in the areas of data, indicators and the system (Tuck & Zalesky, 1994), the current set of indicators for the PROTUS process were analyzed and the results from the first two parts of the test are presented in Table 6, where each measurement has been assigned a white color if the criteria are to be fulfilled, a black color if it is not, and a grey color if it is unclear.

The analysis shows that there are a few problems with the current measurement system. The various figures of open reports are all available directly from the system, but they are lacking in accuracy since all sorts of reports are included that are not representative, i.e. reports from old projects that have simply been let be and are left in the system. The figures are however constantly updated and the cost of collecting them is low. The security criterion, i.e. whether there are privacy or confidentiality concerns (Tuck & Zalesky, 1994) is fulfilled for all since the figures can only be viewed by people that have access to the system or measurement site. As for the validity criterion, i.e. whether changes in the value are clearly desirable (Tuck & Zalesky, 1994), it is not certain that a lower number of open reports necessarily represents a better state, even though many speak of the need to reduce the number of reports. Lowering the number of reports could be achieved by simply cutting projects, which is not necessarily desired. The same logic can be applied on the evaluation criterion, which concerns the issue of interpretability (Tuck & Zalesky, 1994), where it is hard to compare the figures with anything, since the pre-conditions to the figures differ from time to time. In projects however, it is possible to compare figures with those of previous projects, but also here it is difficult since even similar projects can differ in shape from one another.

The lead-time indicators suffer from similar problems in terms of accuracy, validity and evaluation. They show the average lead-times of all reports in the system which makes it hard to assess the state of the current process, and for reports that have not been set to certain statuses, no data is included, which means that the indicators do not show the total lead-time statistics. These figures are thus only partly useful for evaluating the process as it were previously.

Table 6. Analysis of current measurements

Indicator:	Data criteria					Indicator criteria		
General Performance Indicators	**Avail.**	**Acc.**	**Time.**	**Sec.**	**Cost.**	**Validity**	**Unique**	**Eval.**
Number of open reports		▒				▒		■
Number of open 100 p reports		▒				▒		■
Number of open reports older than x weeks		▒				▒		■
Number of open reports older than y weeks		▒				▒		■
Number of open reports older than z weeks		▒				▒		■
Problem Solving Performance Indicators								
Percentage of Root Causes registered (closed)		■					▒	
Percentage of Root Causes registered (status 39)		■					▒	
Technical Root Cause identified	▒	▒			■			
Systematic use of problem solving tools	▒	▒			■	■		
Planning Performance Indicators								
Number of Reports unplanned older than 4 weeks		■						
Percentage of Reports closed on time		■						
Percentage of Reports planned before closure	■	■						
Number of Rescheduled Closure weeks						▒		
Leadtime Performance Indicators								
Leadtime status 1-3	■	■						
Leadtime status 1-39	■	■						
Leadtime status 1-8		■						
Project measurements						▒		
Opened reports last week						▒		
Open reports (1p, 5p, 25p, 100p)						▒		
Open reports (25p, 100p)						▒		
Open reports (Statuses 10-35)								
Closed reports last week								
Unplanned reports older than two weeks		■						
Expected closures		■						
Number of reports closen on time last week		■						

Legend:

■	Criteria are not fulfilled
▒	Unclear if Criteria are fulfilled
	Criteria are fulfilled

The problem solving performance indicators are an interesting effort to examine the quality of the solving process, but they all indicate past events with exception for the Percentage of Root Cause registered (status 39). This indicator is improved by assuring that the root cause has been found before entering the verification phase, which is in line with Walsh's (1996) notion that focus should be on drivers and not outcomes. The indicator aiming to show how large proportion of the reports for which the technical root causes have been found is based on just a selection of reports, and the root causes that are analyzed are those that are entered in the system, which are not always extensively elaborated which was discussed in the root cause analysis discussion in the previous section. Therefore this indicator fails to fully fulfill the availability and accuracy criteria (Franceschini, Galetto, & Maisano, 2007), as the found root causes are not always entered and those that are entered are not always fully explained. It is also a costly indicator since it takes time to review the root causes. The indicator for systematic use of problem solving tools is likewise problematic as the tools used are not always entered in the reports, and problem solving tools are not always needed to solve reports, which means that this indicator does not fulfill the validity criteria.

The measurements of unplanned reports and expected closures could be considered as drivers since they affect the outcomes. However, the measures used in projects and at PE in general are not based on the same conditions, where the general PE figure discards reports newer than four weeks, whereas the project figure discards those older than just two weeks. This makes the measurements prone to misinterpretation and it would be desirable to set a standard definition.

The expected closures indicator is also not very reliable, seeing how several engineers feel pressured to set a closure week based on guesses, which naturally results in reports not being closed on time, which is another indicator used by both PE in general and in projects. The combination of expected closures and reports closed is motivated in that it enables control and evaluation of how well the prediction works, and evaluation is one of the three basic functions of indicators according to Melnyk (2004). It does not tell, however, to what extent the planned closure weeks have been exceeded before closing, and it does not always matter very much if a report is just one week overdue. This figure is not reliable either, as a closure week can be set at any given time, for instance right before the report is closed, which would result in false positive statistics.

The figure showing the number of closed reports during the previous week is objectively true in that it shows exactly the amount of reports closed in that week. However, it poses a risk of encouraging overcontrol (Scherkenbach & Deming, 2001), when the closures can vary on a weekly basis, and a low number of closed reports in a certain week might not be caused by a change in the process performance. It also fails to meet the validity criterion, since while on the one hand it is desirable to close as many reports as possible, but on the other hand it would be better if there were fewer reports to close in the first place.

The third part of the test is the measurement system criteria test, in which we find the balance of the indicators to be quite skewed and focus is on numbers of open reports, lead times and little on quality, which does not follow Ferdows & De Meyer (1990), who argue that primary focus should be on quality for optimal performance. This is also in line with Tangen (2003) who argues that sub-optimization can be achieved when focusing on one area. Another risk of measurement initiatives is according to Parmenter (2007) that employees might see them as control devices solely for management, and that they might circumvent the desired outcomes only to fulfill the desired measurements. Engineers setting closure weeks based on guesses is an example of this at Volvo. The measurement system is also not complete in that it does not cover improvements and learning, i.e. outcomes of the process besides closed reports. Nor the usefulness criteria (Franceschini, Galetto, & Maisano, 2007) can be said to be fulfilled since most of the measures are not used today, and most of the measures only show historic performance, which do not say anything about the current state of the process.

The Three criteria test consists of questions on three areas; strategic, quantitative and qualitative (Franceschini, Galetto, & Maisano, 2007). When applied on the current measurements in the PROTUS process they align behavior and strategy to some extent, but not fully. The total number of, and incoming, reports enable resource planning in terms of allocating resources to projects which have a high number of incoming and existing reports. However, a large part of the lead times consist of verification, in which not much input from design engineers are required, which can result in the interpretation of there being heavier workload than what is actually the case. The closure week indicators also enable resource planning in that they help predict future report levels, but as discussed earlier they might contribute to hasty setting of closure weeks which result in resource planning based on false statistics, which contradicts the TQM cornerstone **Base decisions on facts** (Bergman & Klefsjö, 2010). As for the quantitative criteria (Franceschini, Galetto, & Maisano, 2007), the measures do point to gaps between performance gaps and current states for the number of reports and having the reports planned before two or four weeks, but it fails to measure learning or process improvements. Among the measurements, only a few are perceived as useful to the most of the organization. What are mainly looked at are the number of reports, planned closures and unplanned reports. The qualitative criteria can thereby hardly be considered fulfilled (Franceschini, Galetto, & Maisano, 2007).

5.3.5 Tools for learning

Garvin (1993) states that "*A learning organization is an organization skilled at creating, acquiring and transferring, and at modifying its behavior to reflect new knowledge and insights"*, and we can see that this is an area that Volvo could capitalize more on, which suggests that in order for a failure reporting process to enable continuous improvement there should be an outspoken demand and a defined process for improvement and process changes based on findings in the system, as learning is not something that occurs naturally but organizations rather tend to favor moving ahead to new projects instead of taking time to learn (Wheelwright & Clark, 1992).

Tools for learning are however available within Volvo, as they have a defined process for improvement work in general based on the Plan Do Check Act cycle, named 3C. There is also a procedure for storing knowledge and requirements for components, namely the Design and Verification Guidelines, but this is not used to a large extent when designing new components. Instead it is more common that knowledge learned individually by each designer is applied, which can be used as long as the employee remains in their position. Consequently, as one PMQ stated, problems often reoccur when there are new design engineers who lack the individual knowledge of their predecessors. Also, these two processes are not linked to PROTUS, so it is hard to determine to which extent the PROTUS process today contributes to changes initiated through 3C reports or knowledge stored in the Design and Verification Guidelines. He, Qi & Liu (2002) argue that in order to maximize improvement, quality tools should be integrated in an organization, which suggests that it would be beneficial to couple the PROTUS process with the Design and Verification Guidelines and the 3C process.

Part VI: Discussion

"The aim of argument, or of discussion, should not be victory but progress"
Joseph Joubert

In this chapter the outcome of the analysis and the academic value of the findings are discussed and reflected upon.

6 Discussion

The purpose of the study is to design a process for reporting, using and following up on prototype failure data in a way that enables continuous improvement in the product development process. This was approached by examining existing literature regarding failure reporting processes as well as theory concerning the various aspects of such a process, and performing a study of the process at Volvo to create a more thorough description on how such a process could be designed in order to capitalize more on the potential for improvement.

Existing literature on FRACAS describes various steps for handling failures, and the PROTUS process at Volvo shows many similarities to the FRACAS process. However, at Volvo there is little effort to assure that the PROTUS process was a closed-loop corrective process which a FRACAS is intended to be (Hallquist & Schick, 2004) (Department of defense USA, 1985). Halllquist & Schick (2004) points out lack of prioritized goals due to different perceptions of the aim to be a problematic issue in FRACAS systems, which we believe is the case at Volvo, or rather that the improvement goal for PROTUS is nearly nonexistent. Rarely did we hear any questions about what had been learned from a report, and we believe that a reason for this is the unclarity in ownership of the reports. The projects determine when and on what criteria reports are to be closed and the coordinators are assigned to a certain project, while the reports are assigned to engineers belonging to subsystems which in turn have responsibility for their own improvement work.

One source of un-utilized potential at Volvo is its existing processes for improvement work, i.e. 3C and DVG, which today are not implemented in PROTUS. A clearer linkage between them could provide positive results, as this would follow the notion of He, Qi & Liu (2002), who argue that integration of quality tools is beneficial for improvement.

Melnyk (2004) argues that performance measurements point to gaps between actual and ideal performance, and Franceschini, Galetto & Maisano (2007) say that measurements have an impact on organizational behavior. The current measurement system at Volvo does not address closed-loop correction but rather stresses closing reports, which we believe is a significant contributor to the lack of improvement thinking. For closed-loop correction to be possible in the first place, however, it is pivotal to perform adequate root cause analyses (Monroe, 2010) on a deep level, and not merely address the physical causes (Okes, 2008). A main component in root cause analyses is the supporting data (Okes, 2008), which suggests that there should be sufficient information available to the SR in the PROTUS process, and thus the quality of the issued reports plays a big part. Several engineers have commented that the issued reports do not always present enough information, which leads to the conclusion that the procedure of writing repots is linked to the performance in achieving improvement.

An additional factor in the FRACAS frameworks present in PROTUS is the approvals before progressing to next steps in the process, where this is done by PMEs and PMQs. This is necessary as management needs to be involved when deciding what sort of solution is appropriate as extensive costs could arise if the engineers were to start working in an inappropriate direction. We argue that this should be a particularly important part of this kind of processes in organizations that develop products whose components are costly and with long lead times, as the effect will be greater. As this is an important part of the process effort should be put in assuring that it works as intended, to avoid wastes e.g. in terms of waiting time before being able to continue developing solutions.

The measurement system employed in PROTUS, or rather the different sets, showed not only problems in terms of non-existent addressing of improvement, but also in other dimensions. Several of the measurements are unreliable as they do not represent the current state, and there are also measurements that are not appropriate to base decisions on. In the case of old reports being included in the measurements, this would be avoided simply if the intended process steps were followed as each report would be put in the right status. Using too many measurements may result in ignored measurements (Franceschini, Galetto, & Maisano, 2007) and a compromise between a few key indicators and more detailed ones can be achieved by aligning the measurement system with strategy (Slack, Chambers, & Johnston, 2007). In Volvo's case we saw many measurements that were not used for any decisions, which indicate that such a balance was not met. As was pointed out in the analysis section, the most important factors in a failure reporting system were deemed to be the quality of input, root cause analyses, developments of solutions, time prediction, ability to make needed decisions along process steps and improvement.

However, as became evident at Volvo, a focus on closing reports and setting planned closure dates might lead to forced closures and false planning statistics. This suggests that it would be more beneficial to focus on the core drivers of the process, such as input and root cause analysis abilities. When focusing on finding reports to close in weeks where the number of closed reports appears to be low, typically reports that are near closure are given attention, which we argue is not optimal. Reports that are soon ready for closure are the ones most under control, and it would be wiser to direct focus to reports that have not yet progressed that far. This highlights one of the issues related to performance measurements mentioned by (Scherkenbach & Deming, 2001), namely the risk of acting upon measurement changes caused by normal variation. This therefore asserts the importance of management being aware of what actions are suitable to take based on variations in an indicator.

FRACAS processes described in theory are generally not very detailed, and based on what was learned from this study, we can understand why. Only one company was studied and in this we could see a high variety of failures, each requiring its own optimal process. However, findings have added to the theory concerning failure reporting in the area of improvement, showing that there must be an outspoken demand for it, and that failure reporting processes do not automatically integrate existing processes into it. Additionally conclusions could be draws in the area of measurements, where we could see that a focus on merely closing reports can have negative effects on learning and also risks attention to be directed wrongly.

Part VII: Conclusions

"If we knew what it was we were doing, it would not be called research, would it?"
Albert Einstein

This chapter presents the conclusions that can be drawn from this thesis by answering the research questions.

7 Conclusions

The purpose of the study is to design a process for reporting, using and following up on prototype failure data in a way that enables continuous improvement in the product development process. The three research questions answered in this section serve to fulfill this purpose.

- *How should the process for using reported prototype failures in a product development environment be designed?*

A process for using reported failures should be designed to focus on finding root causes to the identified failures and implementing changes that prevent the failures from reoccurring. This is done by having an outspoken demand for such improvement that does not merely adjust the identified flaws in the products but also addresses the underlying causes to these failures. The process should also be designed in a manner that provides the relevant parties to progress by assuring that needed decisions can be made. The process should be supported by a reporting system that enables issuers to supply sufficient information into the reports, and also enables updates on the state of the issues. A potential problem when designing the process is the amount of actor's involved and the high variety in the input.

- *How should failure data be reported to support improvement?*

The data should be reported according to clearly defined instructions on what to include in the reports in terms of descriptions, pictures and people present when discovering the issue along with contact information. Also just providing the data solely in a report is often not enough, instead the process must support additional interaction between the user and the provider of the data.

- *How can indicators be used to follow up the process for handling reported prototype failures and how can they be used to facilitate improvement?*

A limited set of measurements focusing on the core aspects of the process could be employed in order to drive desired outcomes. In a failure reporting process in product development the most important factors are identified as the input, root cause analyses, developments of solutions, time prediction and the ability to make necessary decisions in the process.

7.1 Future research

This report addresses the issue of how a process for using reported failures should be designed to enable continuous improvement by analyzing a currently employed process from which insights were presented. A possibility for future research could be to investigate the cost of the poor quality generated due to failures not being prevented and thereby get a better understanding of the value a process that manages to learn and prevent future faults actually brings. Another interesting possibility that could help deepen the understanding of the issues related to FRACAS processes and how they could be handled could be to conduct an in-depth study where a few reports are closely followed from initiation to termination.

Part VIII: Managerial implications

"It is always safe to assume, not that the old way is wrong, but that there may be a better way"
Henry F. Harrower

Here the managerial implications are discussed and suggestions for improving how Volvo PE can improve the PROTUS process and thereby increase their ability to learn from the process are presented.

8 Managerial implications

Throughout this study Volvo's way of working with prototype failures was analyzed with the use of theory from several fields. Based on the findings several suggestions for improvements for Volvo are presented in this chapter.

The issue for Volvo does not lie in their ability to capture failures. Indeed their ability to do so today is well developed; in fact the act of reporting failures is encouraged and is today an integrated part of the product development process. Instead the main problems observed throughout the study are related to two areas: The RCA and an ability to diffuse the knowledge generated in the PROTUS process in a manner that allows organizational learning from the mistakes and helps addressing the underlying causes to the observed issues. Today a clear connection between the PROTUS process and process improvement activities and methods such as 3C is missing. Moreover new insights and knowledge in regards to the design of the process are often missed and not transferred to the DVG as intended. The same goes for the ability to facilitate and utilize this potential resource for knowledge that the PROTUS database represents. Instead this is at most done sporadically and relies on individual efforts and initiatives rather than being a part of the daily routine and culture.

Create a connection to 3C and DVG
Objective: Capture improvement potential.
Benefit: Increased learning and prevention of reoccurring failures.

Today the gap between the PROTUS process and the DVG and 3C is indeed the missing link and we suggest that in order to incorporate learning into the process that a new process step should be included that could act as a bridge between PROTUS, 3C and DVG. This process step could be introduced right after the root cause analysis step, where an enquiry is made on whether or not the fault could have been avoided. If so, this should result in an action, where a 3C report could be required for instances where a process change of considerable complexity has been identified or a modification or addition to the Design and Verification Guidelines of the concerned component could be required for less complicated issues. This would both initiate a more outspoken demand for more thorough root cause analyses and provide a clearer link between the systems at Volvo. Just asking the question and integrating it into the system would be valuable since it would raise awareness and get people to start thinking about potential improvement opportunities.

For the connection between to 3C to be successful there has to be a mechanism that ensures that potential process improvement areas are not lost as they risk being today, since today there is no one who is responsible for identifying suitable reports. Instead once the projects accept the closure of the report there is no longer an owner to the problem unless someone takes an initiative and handles it over to another part of the organization, and even then it is not possible to get the full picture of what the effort has resulted in. Therefore it becomes difficult to follow up what changes were made to the process based on the initiative and find out if the cause written in the report actually was resolved.

Moreover the mechanism must also be able to make an initial selection of reports that are believed to prove most beneficial as improvement projects, taking into consideration the estimated benefits and cost of the improvement project. This has to be done since we believe that there otherwise would be too many reports to manage. Furthermore it is also likely that not all report can be used as a starting point for improvement projects nor is it likely that all reports would offer cost-effective improvement possibilities providing further rational for the need of a selection mechanism..

Therefore we suggest that this selection should be made by those responsible for closing the report (today the PMQ and PME), who then in turn will notify the coordinator of these reports. The coordinator will then be responsible for handing over these reports to the Quality, Processes & IT department who will be responsible for the final selections of reports and could then based on their knowledge initiate 3C reports when warranted.

An alternative is that the SR could grade the report in terms of feasibility for the change and in terms of expected benefits. Then suitable candidates could be selected based on this grading and on the comment written on how the faults could have been avoided. This could for example be done by letting them answer two questions by grading them on a scale, where one question deals with the estimated value a change to the process would provide and the other question deals with how much effort the SR believe is required to change the process. Of course such a selection is not perfect by any means but we argue that in this case there is a tradeoff between the resources required to make a suitable non-biased selection and the value that a more accurate selection would bring.

There is also a third alternative available if PE decides to keep doing regular audits on the quality of the root causes found in the reports, in which the selection could be done at the same time as the RCs are evaluated. The downside with this alternative compared to the others would be that the time required to take corrective actions would increase and the evaluation of the RC would be more time consuming.

For the DVGs to be updated frequently we believe that there has to be an outspoken demand from management for this to happen and perhaps the best way to incorporate this would be to have designated time allocated to the design engineers for this sole purpose. Introducing dedicated time for this activity would make it easier for the design engineers to prioritize this activity while also signaling that activity is considered to be important. It deserves to be mentioned that for the DVGs to have any value it is essential that they are actually used when developing new components.

Reoccurring audit on reports
Objective: Ensure continuous improvement of the PROTUS process.
Benefit: Improved performance over time of the PROTUS process.

As a means to facilitate continuous improvement of the PROTUS process itself we suggest that there should be a recurring audit of a sample of PROTUS reports, including for example reports deviating in lead-time and reports from which there have been indications that the process for solving the faults has not worked as intended. The audit should consist of an investigation of the causes to the unwanted or deviating behavior, in order to find new ways to improve the process. Candidates for this audit could be selected when the reports are closed. Then if the audit uncovered an area for improvement a 3C report could be created in order to lead the process improvement effort.

For this activity to work there has to be a clearly designated owner who is responsible for carrying out the audit and securing that reports are sampled for it. The owner also has to ensure that a 3C report is created when the investigation warrants it. A suitable candidate for this activity could for example be Volvo's Quality, Processes & IT department since they are leading many 3C errands.

Improve PROTUS report quality
Objective: Clarify how the faults reported in PROTUS should be described.
Benefit: Easier for the SR to start working with the RCA and for readers to get insight into the reported issue.

In order to perform better RCA changes are needed in both the input to the process and to the RCA process itself. In order to improve the input to the process we suggest that some guidelines for the report should be included in the PROTUS system. For example the report could have some predefined headings or questions that ensure that the issuers always are aware of what type of information that is demanded.

- Where and when did the failure occur? Describe the environment in which the failure occurred.
- Describe the events that lead to the failure (if possible describe it as a story)
- How was the fault discovered?
- Describe the nature of the failure, what is the problem? Possible causes?
- If a part was broken, has it been replaced? If so, did this resolve the problem? Where can the broken part(s) be inspected?
- If the issuer is not the one who observed the fault, please provide the originator's name, e-mail address and phone number.
- What actions have been taken to handle and/or contain the problem? What actions are planned?

The rationale for having guidelines on how to write the report directly incorporated in PROTUS is to improve the content and the readability of the report. Moreover since not all issuers use the system on a daily basis this would act as a guide for them and help them to provide the information needed. By providing this information directly in PROTUS one potentially unnecessary step for the issuer is also eliminated, since the issuer no longer has to search for any guidelines and they will always be available when needed. Based on the limited time that is available to an issuer we believe that spending time to look for guidelines and to read them is often down-prioritized in favor of more urgent activities, and therefore guidelines that they are not automatically exposed to will be of little value for the daily routine, except for as an introduction. Therefore the design of the guidelines also has to be balanced between the help that they provide and the length of the guidelines. If they are too long, or too complex instead of being short and concise, the likelihood that they are ignored is increased.

Additionally it would be valuable to conduct audits on the input quality of the reports, where the quality of the problem description and the information provided in the report is assessed according to a set of predefined criteria's. By so it becomes possible for the organization to get an understanding on the input quality to the process. However for such an effort to actually be valuable we argue that this activity also has to provide feedback back to the issuers in order to improve the long term performance of the input quality.

Improve the RCA in terms of quality and depth
Objective: Ensure that the root cause analyses are conducted on an appropriate level and supplying the engineers with tools for the RCA.
Benefit: Increased root cause analysis capabilities and more underlying problem causes found.

Throughout the interviews a picture emerged of the RCA as being something that was rarely addressed with a structured approach and that little training had been offered to the SRs in terms of methods and tools to use in RCA. In addition we also had the impression when talking to SRs that many times the problems were of a simple nature and required little or no effort to uncover the cause and identify a solution that would satisfy the project. In terms of understanding the goals and the purpose of the process we perceived that the basic value of conducting a RCA was understood but what was required of the SRs in terms of requirements and goals for this activity was poorly communicated. Therefore we argue that the use of the RCA within the PROTUS process has to be clarified in the GDI. This includes the goals of the RCA, the role it plays in the PROTUS process and what the expectations are on the SR in terms of what they are expected to accomplish and how it should be accomplished. In this description the desired level of the analysis should be included to ensure that the SR are aware of how deeply the problem should be investigated i.e. when the root cause can be considered to be found and when the level of analysis is considered to be of an acceptable depth.

Based on this we suggest that there should be an introductory course offered to new and current design engineers. During this this training session we suggest that Volvo should introduce some simple tools for RCA such as five why analysis, Ichikawa diagrams etc. and let the engineers apply these themselves to a simple case in order to promote learning by doing and to show the value of these tools. Furthermore, to clarify the value of the RCA we suggest that this activity should be included in to the GDI describing the A, L, P report process. This would make the PROTUS process GDI more complete. Moreover it would help with forwarding a standardized view of the use of RCA in the PROTUS process and could therefore be used as a starting point for homogenizing the use of the RCA.

To improve the RCA we would also like to see more management commitment from the organization. By this we mean that management, especially group level management should pay more attention to the investigation of the root cause(s) and ongoing RCA within their group by actively following up reports and asking probing questions.

Redefine purpose of the PROTUS Team Meeting (PTM)
Objective: Clarify the purpose of the PTMs and improve their value.
Benefit: More effort directed toward the early phases of a report providing more possibility to affect the end result and ensure the quality of the solution.

Today the meetings are used for a number of different reasons and there are varying opinions regarding the purpose and the value of the PTMs, which are not always in line with each other. Based on this observation we argue that Volvo first of all needs to define and clarify what the purpose should be with these meetings and then make sure that this purpose is known to the participants of the PTMs.

We suggest that the PTMs foremost should be used for decision making related to the reports that the SR cannot make themselves. We further suggest that the PTMs should mainly be used for ensuring that the verification fulfills its intended purpose i.e. the verification is adequate for the intended solution, that the timeframe is acceptable by the project i.e. release of solution will not impact the timeframe of the project and thereby cause delays and finally that the RC is deemed as acceptable and when the report allows for it define closure criteria.

When possible the project should strive towards defining closure criteria as early on as possible. Doing so would bring two main benefits. Firstly the closure criteria would act as a guide for the SR clarifying the goals and the requirements for closing the report and thereby providing the SR with something more tangible to work towards while also making it more clear what the project’s expectations are. Secondly it would when the closure criteria are fulfilled and if the standard of the closure criteria are high enough be possible to close the reports outside of the PTMs. This is beneficial since it allows for more time to be directed towards newer reports where it is more likely that the outcome can be affected or alternatively the projects could elect to have fewer PTMs and thereby release resources that could be used elsewhere instead.

Adapt PROTUS to handle system faults

Objective: Improve PROTUS's ability to manage system faults (faults which cannot directly be assigned to a specific part or where the fault is caused not by a single part but by the system itself).

Benefit: Improved routines for dealing with system faults resulting in more controlled and manageable solution development and reduced lead time.

Today the system only supports the fault reports to be linked with a single part number (the lowest chain of building blocks in the prototype) which stands in contrast to the procedures found in the FRACAS framework earlier presented in Table 4 This framework recommends instead failures to be broken down to the lowest level possible. The current way the system handles problems and part numbers does not translate well to all problems reported since it can be difficult to initially attribute a fault to a single part due to the nature of the fault. Either since the fault is not directly attributable to a single part or since the problem and/or the cause(s) at the time of report issuing is not understood at the level needed for the problem to be isolated to a single part.

Consequently, the current PROTUS system and PROUTS process design result in a few problems. First of all the way the faults are reported today creates problems when selecting the SR for the report, since the one who is responsible for the part is even in the case of a system fault usually the one who is set as SR. This could in turn result in delays, complicate the RCA and the development of a solution. Moreover it is possible that the SRs who are just owners of a single part are not always the most suitable candidate to lead the investigation, since they might not have the system understanding required to find a solution and they might not always be prepared for this type of problems. If the problem requires several investigations on different components and cooperation across line units it is also possible that the SR will have to dedicate more of their time to manage the communication and to oversee and steer the overall situation of the corrective actions. In this case we argue that the overall roll of the SR changes from designing and solving a problem to leading the development of a solution. If this is indeed the case then it would be advisable to make some changes to both the system and the process to accommodate this problem.

Therefore we suggest that the system should be adapted so that the faults can be reported on a system level instead of a part number level when necessary and if applicable the system owner should be set as SR instead of the owner of the part. We also suggest that the procedures for how faults are handled should be reviewed and that new procedures or guidelines for dealing with system faults should be developed. For example a few SRs mentioned that they though the way QJ reports are dealt with works better and could act as source of inspiration when overseeing possible changes.

Improve current documentation
Objective: Improve the documentation describing the PROTUS process and its workflow.
Benefit: Clearer documentation that is more useful for actors within the process.

The current documentation could be improved trough creating documentation that fits each role in the process, for while the GDI is important for understanding the reporting procedure it is too long and not adapted to for example the SR role in the process. Therefore a simple guide for the steps in which the SR are responsible for would be valuable as a checklist and as a guide to new employees and to present the process from a suitable point of view for each actor. The GDI could also be updated by including the RCA activity, by describing how PTMs should be used and by describing how the closure criteria should be set.

Furthermore the documentation could be improved in terms on how each role in the process is described which would clarify better the different actors' needs, responsibilities, and the expected procedures. We also suggest that the overall goal of the process should be clarified and that the documentation should cover the entire corrective action process and not just the report handling part as it does today.

Introduction to PROTUS
Objective: A more unified way of working
Benefit: More coherent behavior from actors within the process

We suggest that new employees who are expected to solve problems handled in the PROTUS process should receive an introductory course in which they are introduces to the process and where they are taught how to work with it, what the goals and objectives are with different parts of the process and what is expected of them as SR. While several SRs see the PROTUS system as simple and easy to use an introduction to PROTUS would be valuable for the organization, since it would serve to introduce standardized procedures for working with PROTUS ensuring that SR does not have to invent and learn their own way of working with the process. It would increase the awareness on what the employees are expected to do and how to act when they are assigned as SRs.

Proposed measurement set
Objective: To employ measurements that improves the way the process is being measured
Benefit: Better estimations of the failure reporting process performance

As discussed in section 5.3.3 Measurements for failure reporting we believe that the most important factors that are appropriate to measure concern the quality of input, root cause analyses, report planning, development of solution, report prediction, decision making, and improvements resulting from the process. The amount of measurements should be kept low in order for them not to be ignored (Franceschini, Galetto, & Maisano, 2007), but there needs to be several in order to avoid the risk of sub optimization (Tangen, 2003). We also argue that the outcome of the process should be measured.

Measuring the quality of the input to the reports and the RCA would be time consuming and difficult to do in midst of the process, which suggests that these are difficult indicators to use proactively in the projects for ongoing reports. Instead they are better suited for reviewing the report issuing and RCA capabilities of the organization at selected times. We argue that as they are drivers in the process we believe that such reviews should be conducted, and the results of the report quality review should be communicated to report issuers. The lead times for ongoing reports for which the root causes have not yet been found, however, could be used in the projects to see whether or not additional help with the analyses is needed. One way in which this measure could be used is to show the number of reports in a project that have passed a certain age before having a root cause entered. A performance measurement does not tell why it has not been met (Franceschini, Galetto, & Maisano, 2007), but this number will alert about concerns and enable further investigation and, if needed, add additional resources in terms of help with analyses. It would be hazardous to set a target for this measurement, however, as the time needed for analyzing different faults can vary, and working towards reducing this number could lead to hasty analyses.

Measuring the lead times from having determined a root cause until having a proposed solution ready for verification could aid in making decisions on what projects to prioritize. It is harder to set up a common limit for when reports would show up in this statistic, however, as the development time varies considerably between component types. Also, if average lead-times were to be used as is done today on company level, the figures would drop whenever new reports have reached the development stage, suggesting that the process is becoming more efficient, when in fact the workload is increased. To overcome this, the sum of lead-times could instead be used. As for the necessary decision making, it could be appropriate to measure the availability of needed decision makers. In the PROTUS-process, the requirement is for the PME and the PMQ to approve the steps, which is done at PROTUS team meetings. Therefore, this measure could consist of meeting attendance, where the target would be one hundred percent. As for the outcome of the process, we believe that the improvement from the process should be measured through an indicator telling the number of 3C reports that have been issued and how many DVG changes have been made as a result of solving a PROTUS report.

In total this amounts to six indicators which focus on critical aspects of the process: **Quality of issued reports, Root cause analysis quality**, **Number of reports that have passed a certain age before having a root cause entered**, **Sum of lead-times from root cause identification to solution proposal, Issued 3C reports and DVG changes** and **Meeting attendance**. A summary of these measurements can be seen in Table 7. All but the last two are such that when altered will likely have a significant impact on the performance and can therefore be considered as key performance indicators (KPIs) (Parmenter, 2007).

Table 7. Suggested measurements

Measurement	Description
Quality of issued reports	A rating that identifies the quality of input to the process. The measurement is produced by a report reviewer monthly.
Root cause analysis quality	A rating that provides a picture of how well the organization performs in finding root causes, measured by performing monthly reviews of PROTUS reports.
Sum of lead-times from root cause identification to solution proposal	A measure of the total workload, both in total and in projects. This measure can be used in order to determine resource allocation.
Number of reports that have passed a certain age before having a root cause entered	This measure serves as a mean to notify management about when and where to direct further resources to find root causes.
3C reports and DVG changes initiated based on PROTUS reports	The number of 3C reports and DVG changes emerging from the PROTUS process indicates whether the process leads to change initiatives.
Meeting attendance	This measure encourages high meeting attendance which enables the necessary decision making in the process. The measure can be performed by the PROTUS coordinators at each meeting.

Improve the fault point grading

Objective: Evolve the report fault point grading system to make it more useful for decision making

Benefit: Easier for the projects to identify and prioritize critical failure reports

We suggest that the fault point system used for grading the reports according to the expected impact the fault is expected to have on the customer and/or the Operations could also be improved by including a second dimension for representing the complexity of the problem. By doing it this way it would become possible to grade the reports both on the how difficult the fault is to solve as well as the expected customer impact and thereby make it easier to monitor and identify critical problems. This would counter one of the potential problems that exist with the current fault point grading, which is that while the fault points sometimes are used for making prioritizations, they do not provide any information about how difficult the problem will be to resolve. As such a consequence of the current system used can sometimes be that reports actually requiring less attention receive elevated attention and resources while reports that would have benefited more from this treatment remain hidden.

The complexity of the problem should be graded early on in the process either in a POM or when the SR receives the report. The grading should then be based upon the problem statement. Where faults that are likely to require extensive modifications or for faults where the problem is diffuse and unclear are graded as more problematic than reports in which the solution appears to be more straightforward. An illustration of these two dimensions can be seen in Figure 14.

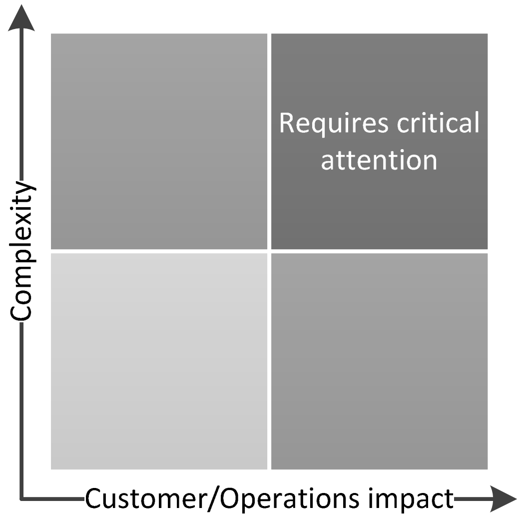

Figure 14. Failure impact vs. complexity matrix

8.1 Summary of suggested changes

A summary of all the suggested changes can be found in Table 8, which also depicts the areas likely to be affected by the change (Process, System & Management) and the suggested priority for each change. The areas likely affected are divided into; changes required to the PROTUS-process, changes required to how the process is managed and changes that are likely to require changes to the PROTUS system itself i.e. the IT systems capabilities has to be adapted in order to support the change. The priority to each change is based on our own rough estimation on the benefits provided through the change graded on a scale between (1,3,5) multiplied by our estimation on the efforts required for the implementation graded on a scale (1,3,5), where a high score represents a greater benefit or a lower implementation effort. For convenience reports that can be initiated as 3C errands are listed as such.

Table 8. Summary of suggested changes

Suggested change:	Areas affected:	Ease*value =Priority
Create a connection to 3C and DVG **(3C)**	Process, system, management	3*5=15
Reoccurring audit on reports **(3C)**	Process, management	5*5=25
Improve PROTUS-report quality	System	1*5=5
Improve the RCA in terms of quality and depth	Process, management	3*5=15
Adapt PROTUS to handle System faults	Process, system, management,	1*3=3
Improve current documentation	Management	5*1=5
Introduction to PROTUS	Management	5*1=5
Introduce suggested measurements **(3C)**	Management	5*2=10
Improve the fault point grading	System, Process	3*1=3
Redefine the purpose of the PTMs **(3C)**	Process, Management	5*3=15

The estimation of the cost and benefit for implementing the faults were based on a few assumptions. In this estimation all changes that are likely to require a change to the system have been assumed to have a higher implementation cost than changes to the PROTUS process and the management of this process, since changes to the system have been assumed to be more complicated and time consuming to implement. The value of the suggestions were based on our judgment on how the change would impact the

PROTUS process in terms of reduced waste and increased learning in both a long term and a short term perspective with an assumed high, intermediate or low impact. It is however difficult at this stage to fully estimate the effort required to implement the suggested changes, since there are often many ways in which these changes could be implemented and the benefits and costs are likely to vary depending on the way a suggestion is implemented. To give an example the effort required in order to create a connection from PROTUS to 3C and the DVG will depend on the approach used to implement this suggestion. An implementation of this suggestion that concerns changes to the PROTUS system would likely require a larger implementation effort in terms of the resources required and the time required for the implementation, while a solution that only requires a local process change at Volvo GTT PE would require less recourses and time.

In the end we recommend that Volvo at first should try to implement some of the simpler suggestions first, for instance some of the new measurements earlier presented in the proposed measurement set section. Considering the potential value that enhanced learning from the PROTUS process could bring we suggest that Volvo should look into and try to implement a connection to 3C and the DVG as soon as possible. Another suggestion that we would recommend to implement early on would be the reoccurring audit on reports, since this suggestion would not be too complicated to implement while it at the same time would support the continuous improvement effort of the PROTUS process.

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Appendix A: Framework for indicator design

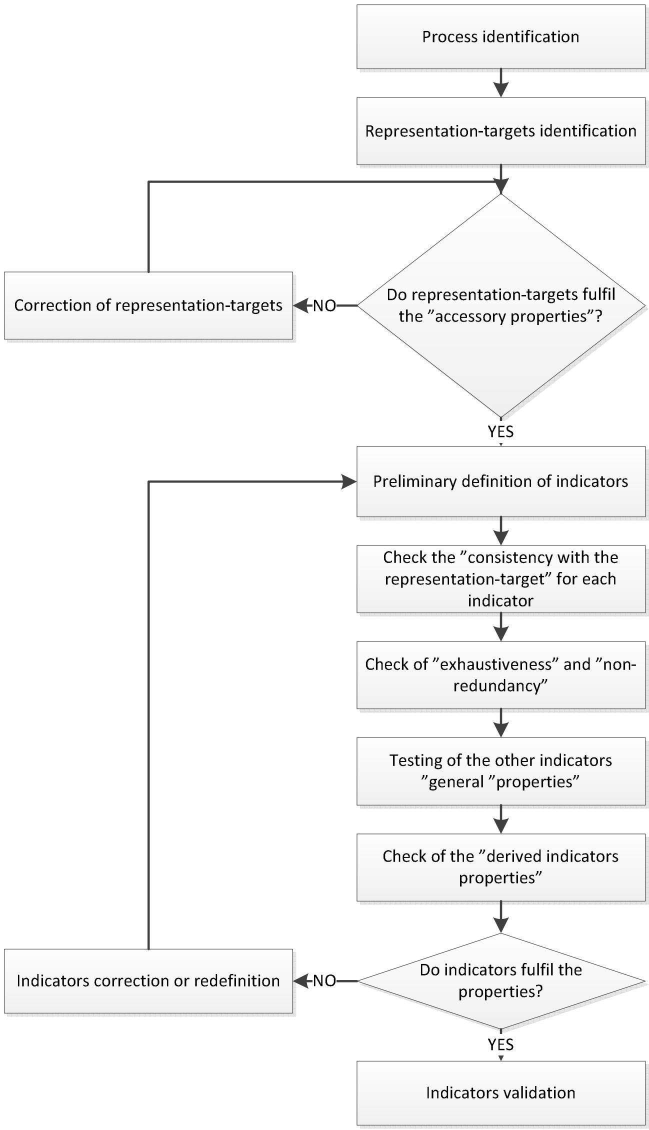

Figure 15. Scheme of operational methodology, adapted from (Franceschini, Galetto, & Maisano, 2007, p. 103)

Appendix B: Additional FRACAS frameworks

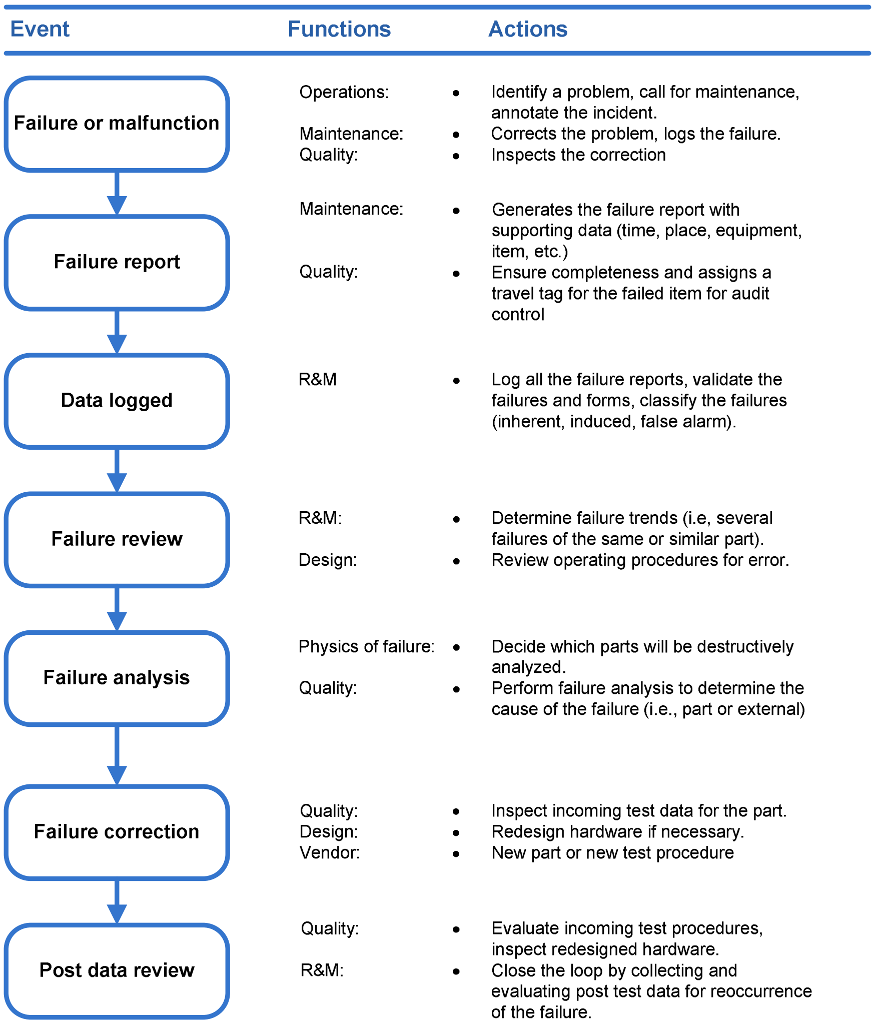

Figure 16. FRACAS framework adapted from (Stockhoff, 2010, p. 936)

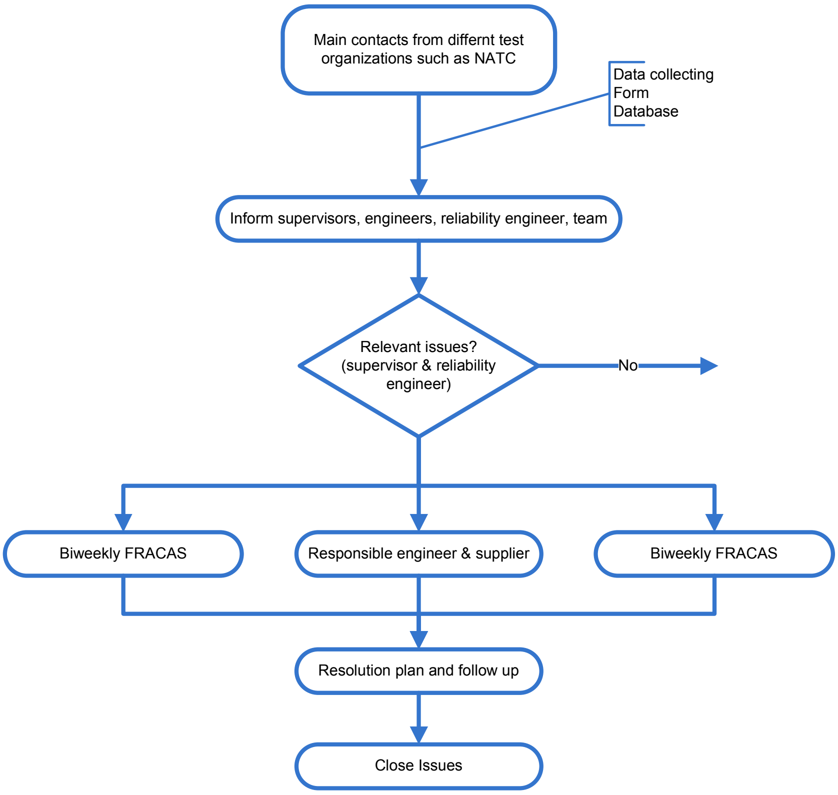

Figure 17. FRACAS framework adapted from (Ling, Hsieh, & Cowing, 2004, p. 9)

Appendix C: A, L, P report statuses explained

Status:	Explanation:
1	Report written
10	Report written and distributed
15	Report has not reached correct solving responsible
19	Report has reached correct recipient, handler accepts the report
2	Report re-issued
21	Incomplete report
22	Verification not approved
3	Investigation & work on solution
31	Work started, investigation started and action plan presented
39	DCN ready for realese, solution proposed
5	Verification
59	OK, ready to close
7	No, action at present
8	Report closed

Color code explanation

Green	Report progressing
Red	Code indicating that a certain problem has occured

Figure 18. Status levels used in the PROTUS failure reporting process

Appendix D: Process map for failure reports

Report status:	1		10			19
Phases:	Fault discovery	Report creation	Administration			Solution
Description:	Identification of observed or potential issue.	Creation of a report describing the fault and its occurance.	Report is checked and administrated to the individual responsible for resolving issue.			
Critical activities:	Discovery & reporting of issue	Report writing & distribution	Checking the report	Accepting the report	Administration of report	Accepting the report
Supporting Activities:						
PTM (currently used in)						•
Report monitoring (by handler)			•	•	•	•
Main Roles:						
Originator	**R**	C				
Issuer	I	**R**	C			C
Handler			**R**	**R**	**R**	I
Solving Responsible	(I)	(I)	(C)		C	**R**
PME & PMQ			C	C		
Expected outcome:						
	Issue reported	Report stored in PROTUS	Checked report	Handler accepts ownership	Report sent to solving	Solving starts
Alternative outcomes from process:						
			Another project responsible for report	Report not accepted		Report rejected by solv
						Report slaved
Critical incidents: (Observed problems in each step)						
	Fault not seen	Report not written	Report missed		Report sent to wrong solving	Incoming report lacks information
	Fault not reported	Incorrect information provided	Errors missed			Report missed by solving
		Insufficient information				Work not initiated
		Report created on a issue that dosen't belong in Protus				

Report status:	3	3&31	39 & 5		5 & 59	8
Phases:	Solution continued...				Termination	
Description:	Solving reponsible accepts the report and proceeds with investigation, works on solution and verification.				The solution along with its verification is accepted by the project. Acceptance of the solution results in the closing of the report and the termination of the process	
Critical activities:	RCA	Development of solution	Verification Plan	Verification	Accepting solution and verification	Closing the report
Supporting Activities:						
PTM (currently used in)	•	•	•	•	•	•
Report monitoring (by handler)	•	•	•	•	•	•
Main Roles:						
Originator	C	C				
Issuer	C	C	C	C		
Handler	I	I	I	I	I	
Solving Responsible	**R**	**R**	**R**	**R**	C	
PME & PMQ					**R**	**R**
Expected outcome:						
	Reason for report identified	Actions to mitigate fault found	Method for verification deci	Solution verified	Report is Ok to close	Closed report
		DCN ready for release				
Alternative outcomes from process:						
	No RC found	No viable solution found		Verification failed	Verification rejected	
	RC is connected to another component			Verification not possible	Solution rejected	
	Report slaved					
	Deep RCA not possible					
	Solving responsible changed					
Critical incidents: (Observed problems in each step)						
	No RCA conducted	solution not developed according to time plan	No time for verification	Incorrect verification	Information needed for decision is lacking	Solution solved from projects POV (component fixed), but process issues are not adressed
	RCA is incorrect		Unclarity on verification requirements	Verification not conducted		
	RCA not deep enough			Low part availability		
	RCA not documented in PROTUS			Verification not conducted according to time plan		
	Missing parts					

Legend

R	Responsible	Responsible for completing the task
C	Consulted	Supports task (with information, testing etc.)
I	Informed	members who are kept up to date on the progress
	Activity	
	Decision	
	Start and stop (process boundaries)	

Figure 19. Current State Process Map for A, L & P PROTUS Failure Reports

Appendix E: Interview guide Solving responsible

Purpose of the interview:
The purpose is to perform an in-depth review of solving responsible engineers' perceptions of the PROTUS process and to map the current actual process (from the point that the solving responsible receives the report until the point that the problem has been resolved).

Target group:
The target group for this interview is users of the PROTUS system working to solve failure reports (Assembly, Laboratory and Project reports). These users are denoted as Solving responsible throughout the report.

Selection of interview subjects:
The sampling for the interviews was first divided into four strata, one for each subsystem at the Volvo Powertrain product development department: Control Systems, Base Engine, Combustion and Transmission. This was done in order to gain input from and to capture differences between the different subsystems. An equal number of candidates were selected for each stratum; three from each subsystem. The interviewees in each stratum were then selected using a convenience sampling method. Suitable candidates for the interviews within each subsystem were based on our knowledge of solving responsible and available lists of solving responsible within each subsystem. Based on this information a list of potential candidates was formed. The final selection from this list was then later based on the availability of the candidates.

Location of interview: Secluded room at Volvo GTT Powertrain Engineering, Göteborg.

Duration of interview: 90 minutes + 30 minutes for initial reflection and summary.

Language used: Swedish

Information storing method: Personal notes and audio recording (if the interviewee consented)

Name: **Role:**
Place in organization: **Time at Volvo:**

Set up and introduction (5 min)

PROTUS usage (5 min)
Hur länge har du använt PROTUS för felrapportering (A,L,P)?

Kan du beskriva PROTUS och dess funktion i ditt arbete (A,L,P)?

Hur ofta använder du PROTUS?

Process knowledge (10 min)
Har du erhållit någon utbildning om den här processen?

Om ja, kan du berätta om den?
Anser du att utbildningen är tillräcklig?

Om du någon gång har varit osäker på en del i PROTUS-processen, hur har du hanterat detta?

Har du sökt hjälp? I så fall, var?

Finns det någon dokumentation med instruktioner för processen?

Om ja, vet du var man hittar den? I så fall, var?
Har du någon gång använt den?
Vad anser du om den?
Har du förbättringsförslag för dokumentationen?
Finns det någon annan dokumentation/information som du saknar som hade kunnat underlätta ditt arbete som lösningsansvarig?

Vad innebär rollen som lösningsansvarig?

The process (PROTUS) (25 min)
Hur jobbar ni i er grupp med PROTUS?

DTL, ledarskap, uppföljning, gruppsammarbete?

Kan du beskriva i stora drag hur du jobbar från att det kommer in en PROTUS-rapport?

Vilka steg är du ansvarig för?
Hur blir du uppmärksammad på att du fått en rapport?
Vad är det första du gör när du fått en rapport?
Om det saknas information i rapporten, vad gör du då?
Om det finns tvetydiga kommentarer?

Hur hanteras de fall då du anser att felet bör hanteras av ett annat projekt eller avdelning?

Hur fungerar det då rapporter rör systemfel och inte en enskild komponent som du ansvarar för?

Finns det någon skillnad i sätt att arbeta mellan olika sorters rapporter?

Mellan A-, L- och P-rapporter?
Mellan olika felpoängsnivåer (1, 5, 25, 100)?

Hur prioriteras rapporter?
Prioritering mellan rapporter?
Prioritering mellan rapporter och annat arbete?
Prioritering mellan olika projekt?

Om problemet är svårlösligt, vad gör du då? Kan du ge ett exempel?

Vilka har du kommunikation med under en rapports gång?

Hur fungerar kommunikationen med dessa?
Mellan avdelningar?
Med ledningen?
Vid beställning av verifiering?
Vid kontakt med issuer?
Vid kontakt med leverantör?

Vad tycker du om PTM (PROTUS team meeting)?

Hur används PTM idag?
Vilka är närvarande på PTM?
Bidrar de till processen?
På vilket sätt?
Kan något förändras?

Vad tycker du om handlerns roll?

Planning (5 min)
Ämnen att ta upp: hur, med vilka, rutiner, uppföljning/uppföljningsvecka
Hur sköts planeringen av rapporten?
När i processen sätts en planerad stängningsvecka för rapporten?

På vad är stängningsveckan baserad?
Stängningskriterier?
Vad händer om en rapport inte är stängd i den stängningsvecka som är angiven?

Root cause analysis (10 min)
Ämnen att ta upp: Definition, syfte, djup, verktyg, dokumentering, stöd från organisationen

Hur går du till väga för att hitta orsaken till rapporten?

Kan du beskriva vad en rotorsaksanalys innebär?

Hur arbetar du med det?

Hur djupt brukar du gå?

Kan du ge ett exempel på en rotorsaksanalys?

Har du något standardförfarande för att hitta rotorsaker, exempelvis någon särskild metodik?

Om inte, känner du till något verktyg för rotorsaksanalyser?

Ex: fiskbensdiagram, 5 Why-analys, felträdsanalys, paretoanalys?

Hittar ni alltid rotorsaken?

Hur gör ni i de fall då ni inte gjort det? Exempel?

Development of solution (2-5 min)
Kan du beskriva processen för utvecklingen av själva lösningen? (övergripande)

Finns det något du skulle vilja förbättra inom detta?

Verification (5 min)
Ämnen att ta upp: Syfte, val av metod (hur görs den? vilka överväganden görs?), dokumentering, stöd från organisationen, ansvar.

Kan du beskriva vad verifieringen innefattar och hur du jobbar med det?

Vilka krav ställs på verifieringen av den framtagna lösningen från projekten och organisationen?
Vad baseras valet av verifieringsmetod och stängningskriterier på? Vilka avvägningar görs?
Vem beslutar om verifiering?
Beställa tester både för verifiering och för att hitta rotorsaken?
Uppföljning av verifiering?

Hur bedömer du att verifieringsprocessen fungerar idag? (Beställning av verifiering, genomförande och ansvar?)

Process outcome
Hur delar ni med er av lärdomarna från PROTUS?

Finns det ett standardiserat sätt att göra detta på? (I din grupp? I företaget?)

Har du sett att fel återkommer?

Känner du till om ett problem leder till förbättringar i produktutvecklingsprocessen? Kan du uppskatta hur ofta ett problem leder till sådana förändringar? (återkoppling)

Om ja, hur?
Behövs det någon förändring för detta?

Resources
Tycker du att tiden det tar att lösa ett problem är rimlig?

Om inte, vad är de vanligaste orsakerna till att det tar längre tid att lösa ett problem än vad som är idealiskt?

Upplever du att du har de resurser som krävs för att lösa ett problem?

Tillräckligt med tid? Kompetens?

Hur upplever du arbetsbördan från PROTUS?

Vilken del i processen är mest tidskrävande? (Tid för RCA? Tid för att utveckla lösningsförslag? Tid för verifiering? Administration?)

För dig räknat i arbetstimmar?
Total tid?

General questions (10 min)
Känner du till på vilka kriterier du utvärderas som lösningsansvarig? Kan du nämna dem?

Tror du att dessa kriterier är relevanta?
Om inte, hur kan man utvärdera lösningsansvarigas arbete?

Vad tror du att andra tycker om processen (PROTUS)?

Vad tycker du om dagens metod med användande av olika statusnivåer för att följa rapporters framsteg?

Har du märkt någon förändring kring hur PROTUS-processen används under din tid på Volvo?

Improvements (10 min)
Har du något eller några förslag till ändringar i systemet, träningsmaterial, dokumentation, kommunikation o.s.v?

Saknas något? Information i rapporter?
Har du något eller några förslag på förändringar i arbetssätt med PROTUS?

Har du något eller några förslag på hur andra parter i processen kan jobba bättre?

Har du någon möjlighet att påverka PROTUS-processens utformning?
I så fall, hur?

Om inte: varför?

Hur bör man jobba med att förebygga och rätta till fel?

Finns det något onödigt i systemet eller processen? Onödiga steg i processen? Onödiga fält?

Tycker du att det är något som vi har missat att ta upp?

Appendix F: Interview guide Managers

Purpose of the interview:
The purpose is to perform an in-depth interview with managers and group leaders in order to get a better understanding of PROTUS and to capture different opinions and views of PROTUS from different levels in the organization.

Target group:
The target group for this interview is managers from different areas in the organization who have a relation to the PROTUS failure reporting system, including group level managers, PMQs, PLVs and PMEs.

Selection of interview subjects:
The sampling for the interviews was mostly based on opportunity sampling. Where interviews were selected based on suggestions from our industrial supervisor and on availability of relevant interviewee subjects.

Location of interview: Secluded room at Volvo GTT Powertrain Engineering, Göteborg.

Duration of interview: 60 minutes + 30 minutes for initial reflection and summary.

Language used: Swedish

Information storing method: Personal notes and audio recording (if the interviewee consented)

Name: **Role**:

Place in organization: **Time at Volvo:**

Hur arbetar du med PROTUS/hur kommer det in i ditt arbete?

Hur arbetar ni på inom er grupp/avdelning med PROTUS?

Uppföljning av rapporter?

Möten?

Hur säkerställer man att lösningsansvarig har den information och verktyg som behövs?

Hur bedömer ni processen?

Målsättning? Jobbar alla inblandade i processen mot samma mål?

KPI:er, performance measurements?

Vilka finns? Hur används de?

Vad anser du om dem?

Vad för utbildning har du erhållit om PROTUS?

Vad är din syn på PROTUS-processen?

Syfte?

Vad fungerar bra respektive dåligt med PROTUS?

Rapporter, rotorsaksanalys, lösning, verifiering, uppföljning, stängning, kommunikation

Vilka åsikter om PROTUS hör du i gruppen och från andra delar av organisationen?

Tar ni vara på erfarenhet från tidigare misstag och lyfter dem vidare i organisationen?

Finns det något man kan ändra på i PROTUS-processen?